Assessment of CHIM-XPT and Watch in Predicting the Calcite Scaling Potential of Geothermal Wells

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Geothermal, wells, calcite scaling, software, Philippines

ABSTRACT

Calcite scaling is one of the problems besetting geothermal energy production. Early detection of the calcite scaling potential of geothermal wells will be helpful in assessing the project economics due to intervention measures that have to be adopted to mitigate calcite scaling or clear calcite scales from geothermal wells, since these will result in additional production costs, as well as formulating the appropriate production well monitoring strategy. Early detection of the calcite scaling tendency of a well can be modeled using geochemical software. This paper assesses the software watch and solveq/chim-xpt, two widely used programs by the geothermal industry, in predicting the calcite scaling potential of wells.

Introduction

As in geothermal production field, steam production is sometimes beset with mineral scaling problems, one of which is formation of calcite scales in production wells. Calcite scaling occurs in wells, drilled at the fringes of geothermal systems or where a carbonate rocks hosts the geothermal reservoir. Wellbore calcite deposition is manifested by a continuous decline in steam production over months to years until cessation of production occurs when the deposit is thick enough to block the wellbore. Removal of the blockage is done either by mechanical clearing using a drilling rig, acidizing or a combination of both. These methods are often expensive and time consuming, aside from production losses while recovering the well output.

Downhole injection of calcite inhibitors may be applied to save on costly workovers. The intervention method to be adopted will depend on its economics. Well discharge testing is a common practice to assess the well output, fluid chemistry, and sustainability during the exploration and development stages. The data collected during these stages can provide information on the calcite scaling potential and well condition at which scaling can occur. Two of the most common computer programs used for modeling the calcite potential of wells, are WATCH, developed by the Iceland Water Group and SOLVEQ/CHIM-XPT (Reed, 1982 and Reed and Spycher, 1984). This study assesses three (3) versions of these programs, namely WATCH Versions 2.1 and 2.4 and SOLVEQ/CHIM-XPT (2011).

Theory Of Calcite Formation

Calcite is a common mineral found in many geothermal systems. It normally occurs, as vein-filling or in interstices in rocks, suggesting that geothermal waters are close to calcite saturation. It also intermittently occurs as scale deposits, in the wellbores or pipelines. Its formation is governed by the following chemical reactions:

$$H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \quad (1)$$

$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-} \quad (2)$$

$$Ca^{2+} + 2HCO_3^- \Leftrightarrow CaCO_3 + CO_2(g) + H_2O\uparrow \quad (3)$$
$$Ca^{2+} + HCO_3^- \Leftrightarrow CaCO_3 + H^+ \quad (4)$$
$$Ca^{2+} + CO_3^{2-} \Leftrightarrow CaCO_3 \quad (5)$$

Arnorsson (1989) indicated that geothermal reservoir waters are generally calcite saturated. Supersaturation and calcite precipitation is deemed to occur soon after boiling occurs, as the fluids move within the reservoir or as it ascends in the wellbore. Equation (3) denotes the chemical reaction in a boiling process. Equation (4) was alternatively suggested by Sanchez, et. al. (2005) as a mechanism for calcite formation from the mixing of supersaturated fluids and hotter, up-flowing fluids.

The available calcium and carbonate species in geothermal fluids, are however governed by complex geochemical processes involving the bulk composition of the fluid, the surrounding rocks it comes in contact with, mineral speciation, and thermodynamic processes governed by changes in pressure and temperature. Modeling a system such as this will require complex calculations involving aqueous-mineral-gas equilibria (Arnorsson, et. al., 1982, Reed, 1982, Reed and Spycher, 1984).

Predicting Calcite Scale Formation

Newly drilled wells normally undergo medium-term discharge tests to assess the chemistry of the fluid and well output, at different operating well head pressures. Several sets of samples are usually collected and analyzed for its gas content, i.e. CO_2, H_2S, NH_3, etc. and water composition, i.e. pH, Na, K, Ca, Cl, SO_4, TCO_2, and other species. The analytical results can be used as input data to chemical modeling programs that are capable of calculating calcite saturation.

Before 2011, WATCH V2.1 was the main program being used by Energy Development Corporation (EDC) for assessing the calcite scaling potential of wells. Recently, two additional programs were acquired, WATCH V2.4, an updated version of Watch V2.1 and SOLVEQ/CHIM-XPT. Owing to differences in thermodynamic data and calculation methodology, said programs, though useful for chemical modeling, yield differing results.

Scope and Limitations

This study was conducted using actual production well chemistry data of wells from the Mt. Apo Geothermal Field (Fig. 1, balloon in light blue) and Leyte Geothermal Field (Fig 1, balloon in blue). The six wells used in the study were selected based on the following criteria:

1. Four wells with known calcite deposits
2. Two liquid saturated wells with no observed calcite deposits

Chemistry data were selected randomly at different well discharge periods. For wells with known calcite deposits, well chemistry used in the calculations were chosen prior to implementation of workover operations to clear the blockage, and subsequent calcite inhibition treatment.

Figure 1. Map of the Philippines Showing EDC Concession Areas.

Assessment Approach

Four data sets from each of the six wells, collected at different dates, were used for the assessment. The data were reduced using the 2 versions of WATCH, i.e. Ver 2.1 and Ver 2.4 and SOLVEQ-CHIM-XPT, utilizing the data reduction procedures specified in the user manuals of said softwares

Watch V2.1, and Watch V2.4 both calculate the speciation of components at a specified downhole temperature. WATCH generates an output that provides the mineral solubility product constant (Log K) and ion activity product (Log Q) for the mineral at the reference temperature and the specified boiling step(s). If Log (Q/K)>0, then the mineral is deemed to be in an oversaturated state

SOLVEQ/CHIM-XPT is a speciation program similar to WATCH that calculates the speciation at a specified temperature. However, unlike WATCH, CHIM-XPT has the option in boiling calculations to specify the type of fractionation (i.e. removal of saturated minerals and gases from the system after each equilibration step) at the specified boiling temperature, namely:

1. Frac=0, no fractionation occurs
2. Frac=1, fractionation of solids only
3. Frac=2, fractionation of gases only
4. Frac=3, fractionation of solids and gases

Table 1. Water Chemistry of Wells Used in the Calculations.

Sampling Date	WHP (Mpa)	Sampling Pressure (Mpa)	H (Kj/Kg)	pH	Li	Na	K	Ca	Mg	Fe	Cl	SO_4	HCO_3	B	NH_3	SiO_2	H_2S	CO_2 Total
										(Concentration in ppm)								
Well APO1D																		
12-Jan-1999	0.85	0.80	1041	6.65	8.5	2933	423	156	0.13	0.13	5273	39.07	28.3	100	0.35	492	2.61	34.0
21-Jun-1999	0.89	0.80	1094	6.55	ND	2939	381	138	0.14	0.00	5277	43.5	29.5	100	0.19	455	6.87	31.2
07-Dec-1999	0.82	0.76	1054	7.42	ND	2980	416	141	0.36	2.44	5300	41.4	21.0	107	0.39	453	3.17	18.4
21-Mar-2000	0.78	0.76	1054	7.22	ND	2940	400	143	0.11	ND	5248	38.6	19.6	105	0.28	473	4.27	19.0
Well MD1D																		
15-Mar-2001	0.80	0.80	1370	7.26	ND	3620	788	75.9	0.02	ND	6129	93.2	39.7	120	0.56	724	4.47	33.8
11-Jul-2001	0.87	0.85	1360	7.21	ND	3460	718	76	0.12	ND	6157	101	48.4	125	0.61	741	8.42	35.3
17-Dec-2001	0.92	0.90	1360	7.51	ND	3366	774	84.8	0.03	ND	6010	149	46.9	121	0.67	710	0.67	37.5
14-Mar-2002	0.92	0.85	1466	7.23	ND	3542	671	122	0.16	ND	6100	123	43.6	123	0.24	592	3.41	35.4
Well APO3D																		
03-Mar-2008	0.86	0.80	937	6.83	ND	3925	475	271	0.35	ND	6803	26.5	10.7	128	0.34	481	3.47	13.4
07-Oct-2008	0.88	0.88	976	5.82	ND	3977	460	288	0.36	ND	6695	27.5	4.3	126	0.55	474	2.03	6.2
02-Feb-2010	0.81	0.80	997	6.25	ND	3843	500	285	0.26	ND	7021	31	7.6	133	0.37	474	1.5	16.1
06-Oct-2010	0.71	0.71	958	6.44	ND	3881	484	319	0.49	ND	7036	32.9	4.6	130	0.37	467	2.46	8.9
Well MG1																		
03-Sep-1999	1.27	1.17	1352	6.57	5.1	1663	285	21.0	0.69	0.15	2868	38.0	51.9	46.0	1.45	668	2.50	50.8
04-Jan-2000	1.16	1.14	1224	7.14	5.0	1765	289	30.0	1.24	0.27	3141	36.0	59.7	41.0	3.42	668	3.30	51.0
28-Jun-2000	1.14	1.13	1234	6.82	5.2	1824	274	20.0	0.74	0.08	2950	39.0	46.0	38.0	3.32	641	1.50	43.5
13-Sep-2000	1.08	1.08	1218	6.67	4.1	1625	244	22.6	0.63	0.06	2712	54.0	53.2	30.0	2.00	598	2.48	51.8
Well MG19																		
31-Aug-2000	2.67	2.66	1083	6.19	6.6	1812	347	20	0.68	0.16	3091	26	62.2	49.0	2.8	655	2.24	80.6
28-Dec-2000	1.20	1.19	1303	6.98	5.5	1866	281	23	0.81	0.15	2932	77.6	50.0	43.0	4.7	630	2.83	43.1
24-Mar-2001	1.17	1.12	1305	6.73	1.3	1875	265	21	0.8	0.08	3054	75	64.5	34.0	4.8	636	5.4	59.2
30-Aug-2001	1.37	1.27	1430	6.88	7.3	2040	371	19.8	0.72	0.46	3472	29	62.6	61.1	2.48	718	3.38	57.2
Well 503																		
08-May-2008	1.25	1.24	1240	6.31	19.8	4530	907	165	0.05	0.32	8284	12.3	15.1	185.0	2.39	669	2.02	29.6
29-Aug-2008	1.36	1.35	1240	6.62	18.8	4446	910	159	0.05	0.05	8312	25.1	15.5	172.0	2.31	672	1.73	22.5
19-Jun-2009	1.44	1.43	1259	5.85	20.2	4590	924	169	0.05	0.05	8379	25.2	6.3	176.0	3.32	665	1.79	20.0
14-Dec-2010	1.24	1.20	1283	6.57	21.1	4729	952	184	0.27	0.13	8538	21.5	15.3	197.0	2.62	659	5.12	19.5

* ND - Not Determined

Table 2. Gas Chemistry of Wells Used in the Calculations.

Sampling Date	(Mpag)	Sampling Pressure (Mpag)	H (Kj/Kg)	CO_2	H_2S	NH_3	He	H_2	Ar	N_2	CH_4
							(mmoles/100 moles H_2O)				
Well APO1D											
12-Jan-1999	0.85	0.80	1041	261.0	2.58	0.26	0.0010	0.1750	0.0880	6.4640	0.0670
23-Jun-1999	0.89	0.77	1094	200.0	6.38	0.32	0.0010	0.2850	0.2420	19.2410	0.1350
07-Dec-1999	0.82	0.76	1054	160.0	6.87	0.24	0.0010	0.2910	0.1570	12.3000	0.0690
21-Mar-2000	0.78	0.76	1054	157.0	8.50	0.24	0.0010	0.4110	0.2890	23.5400	0.0930
Well MD1D											
15-Mar-2001	0.80	0.80	1370	310.0	14.20	0.55	0.0008	0.8220	0.0680	5.1470	0.0800
11-Jul-2001	0.87	0.85	1360	302.0	13.00	0.43	0.0006	0.7430	0.0690	4.8700	0.0800
17-Dec-2001	0.92	0.90	1360	270.0	12.90	0.49	0.0008	0.7700	0.0640	4.7500	0.0770
14-Mar-2002	0.92	0.85	1466	282.0	14.00	0.44	0.0008	0.7780	0.0480	3.6600	0.0730
Well APO3D											
03-Mar-2008	0.857	0.80	937	87.1	5.37	0.29	ND	ND	ND	ND	ND
07-Oct-2008	0.88	0.88	976	90.4	6.44	0.36	0.0004	0.0688	0.0669	3.8162	0.0397
02-Feb-2010	0.81	0.80	997	105.0	6.08	0.32	0.0003	0.0599	0.0563	3.1580	0.0380
06-Oct-2010	0.71	0.71	958	101.0	4.44	0.25	0.0004	0.0709	0.0814	4.8367	0.0459
Well MG1											
03-Sep-1999	1.27	1.17	1352	720.0	13.60	1.80	0.0020	5.4360	ND	91.2720	18.4130
04-Jan-2000	1.16	1.14	1224	771.0	12.90	0.75	ND	0.9960	0.2400	14.8600	4.1940
28-Jun-2000	1.14	1.13	1234	580.0	14.00	1.56	ND	0.3500	ND	10.9530	1.5900
13-Sep-2000	1.08	1.08	1230	595.0	12.70	1.25	ND	0.7790	ND	7.1460	2.6320
Well MG19											
31-Aug-2000	2.67	2.66	1083	1039.0	18.60	1.96	ND	0.3870	ND	4.1330	2.4390
28-Dec-2000	1.20	1.19	1303	458.0	7.80	2.33	0.0010	0.8610	0.0600	4.3830	1.0390
24-Mar-2001	1.17	1.12	1305	871.0	14.10	2.20	ND	4.0630	0.1570	12.1420	3.6290
26-Jun-2001	1.17	1.16	1449	907.0	31.30	2.71	ND	1.5790	0.0500	4.1800	1.4910
Well 503											
08-May-2008	1.25	1.24	1240	122.0	14.10	1.11	ND	0.7180	0.1080	8.1550	0.2180
29-Aug-2008	1.36	1.35	1240	105.0	16.70	0.90	ND	1.2070	0.0960	7.4220	0.3510
19-Jun-2009	1.44	1.43	1259	86.0	20.70	13.30	ND	2.0600	0.0800	8.1080	0.2900
14-Dec-2010	1.24	1.20	1283	155.0	10.90	1.19	ND	0.0760	0.0080	0.4710	0.0410

*ND - Not Determined

CHIM-XPT expresses the saturated gases and/or solids formed, in each step, in grams or moles.

WATCH calculations can be likened to CHIM-XPT at frac=0, since there is no actual separation of the solid and gas phases. The calculations assume that saturated solids and gases at the boiling step are still involved in the reactions. However, unlike WATCH, when CHIM-XPT precipitates a scale mineral, the material in the scale that was formerly dissolved material is removed from the aqueous phase, which affects what can subsequently precipitate. The effect is greater if minerals are fractionated (Frac = 1 or 3), but it also applies to the unfractionated case. CHIM-XPT, at frac=3, on the other hand, assumes actual phase separation of solids and gases as it boils and are not anymore involved in the succeeding calculations. Thus, for this study CHIM-XPT calculations were limited to frac=0 to have a comparison with WATCH calculation processes and frac=3 to simulate phase segregations when the fluid boils, as it ascends through the well bore.

Aside from the phase segregation options, the differences in the calculations between WATCH and CHIM-XPT lies in the reference fluid used at each boiling step. WATCH always uses the original fluid as reference, whereas CHIM-XPT uses the calculated values of the previous boiling step as reference.

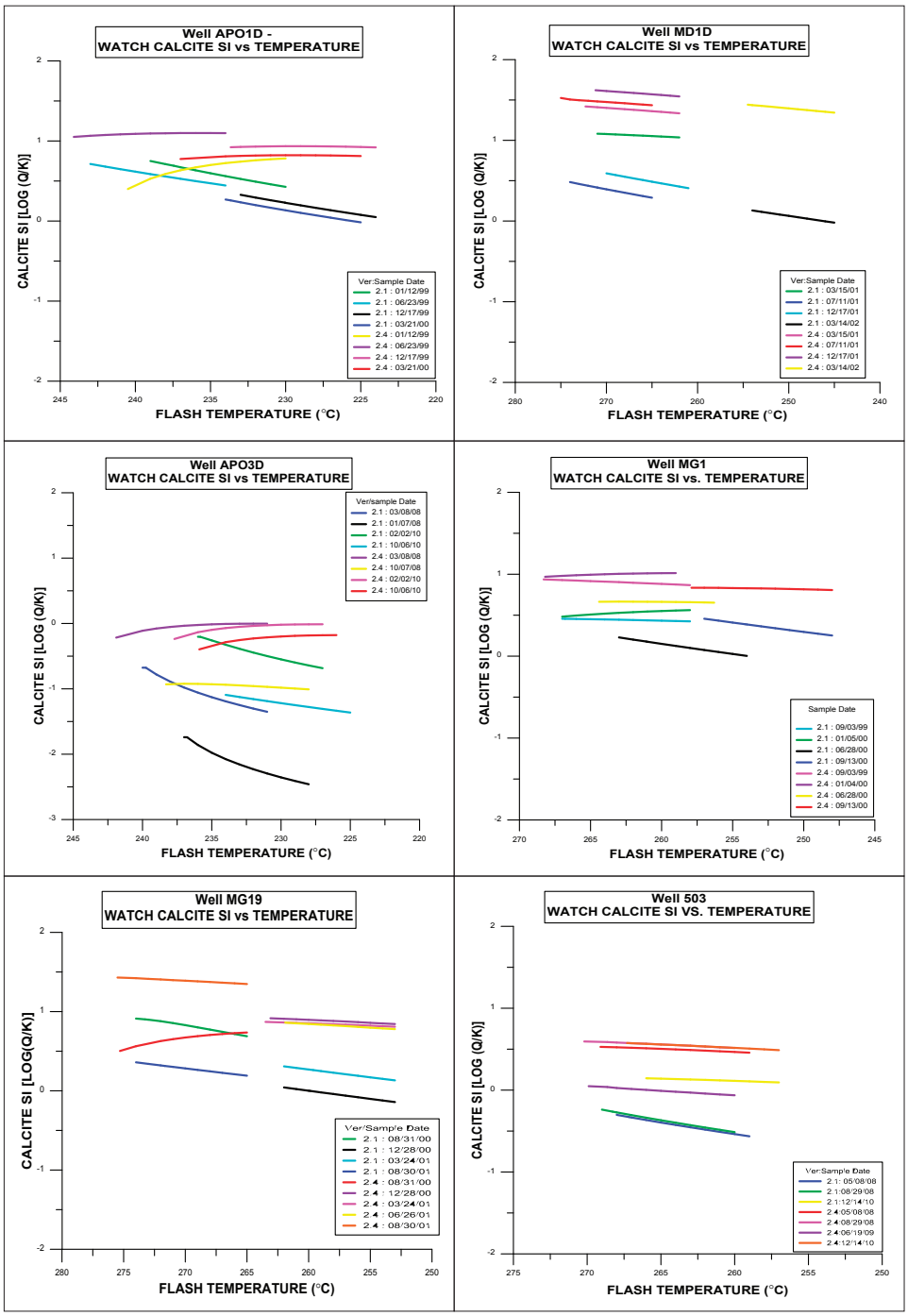

Figure 2. Graphs of WATCH Outputs of Calcite SI vs Flas temperature. Negative Values Indicate Undersaturated Conditions to Calcite.

For CHIM-XPT, the fluids were boiled from the calculated Tqtz, as starting temperature, up to 160°C at 1°C increments for each boiling step. Although the same boiling increment was used for WATCH, boiling is limited to 10 steps. The calculated saturation index (LOG Q/K) for calcite in the case of WATCH and mass of calcite formed, in the case of CHIM-XPT, were extracted and plotted for analysis.

Results of the Study

The water and gas chemistry used in the calculations are shown in Tables 1 and 2. The graphs of the calculated calcite saturation indices (Log Q/K), for the six wells from both versions of WATCH, are shown in Fig. 2. The calculated

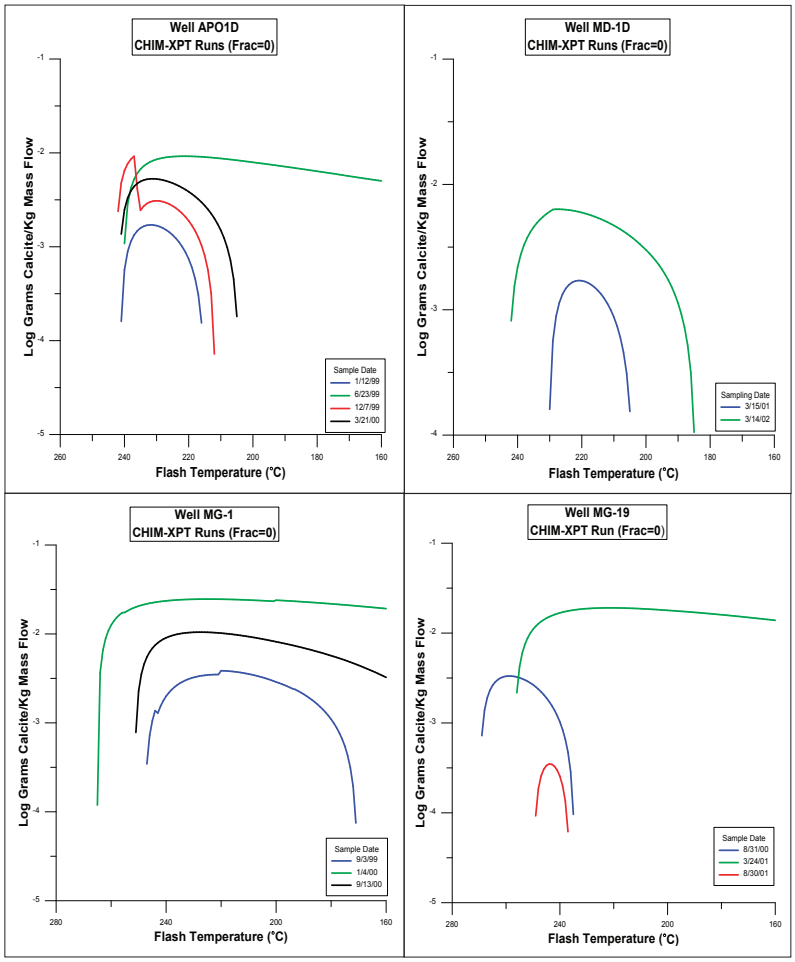

Figure 3. CHIM-XPT Graphs showing Log grams of Calcite in the fluid at the flash temperature at frac=0.

weight of calcite fractionated at each boiling step, per kilogram of mass, from CHIM-XPT calculations, are shown in Fig 3 and 4, for Frac=0 and 3, respectively. Note, however, that there are no CHIM-XPT output plots for wells 503 and APO3D since said wells are undersaturated in calcite. A summary of the calculated calcite saturation index (SI) values for all wells is given in Table 3.

Using WATCH, all the wells known to form calcite blockages have saturation indices (SI) predominantly greater than zero indicating oversaturation with calcite. The degree of oversaturation varies, with well MG1 being the least saturated, while well MD1D shows the highest saturation. Calculated values between V2.1 and V2.4, consistently show higher calculated SI using the latter, suggesting differences in the thermodynamic data used in both versions.

CHIM-XPT similarly shows calcite oversaturation at both frac=0 and 3, for wells MG1, MG19, APO1D, and MD1D confirming that they are oversaturated with respect to calcite. Also, at Frac=3, said wells show that oversaturated conditions only prevail over a few degrees and occur within a few degrees from the onset of boiling. This mimics Arnorsson's (1989) supposition that the boiling process results to a consequential decrease in CO_2 partial pressure as it separates froom the liquid phase along withsteam formation. This leads to calcite supersaturation and precipitation. As the fluids continues to boil to lower temperatures, the fluids subsequently become undersaturated with calcite, owing to continuing separation of the gases and the increasing solubility of calcite with decreasing temperature. This phenomenon of oversaturation with calcite at Frac=3 exemplifies the occurrence of deposits in most wells with calcite blockages. Calcite blockages are normally thickest close to the point of onset of boiling in the wellbore and normally tapers off or disappear as the fluid further boils and cools.

This phenomenon will explain why the coiled tubing in calcite inhibition systems are set below the perceived flash point in wells being treated, i.e. to allow the inhibition chemical to mix and react with the fluid to prevent calcite formation, before it reaches its boiling point.

Using both versions of WATCH, well 503 showed possible episodes of calcite oversaturation despite said well showing no prior indication of calcite blockage formation, while Well APO3D consistently showed undersaturation to calcite. Using SOLVEQ/CHIM-XPT, both wells indicated undersaturation to calcite.

The results of the study show that although WATCH accurately predicted calcite oversaturation for the four wells with known calcite blockage formation, it also indicated oversaturation in a well which has no historical calcite blockage formation throughout its long discharge history. On the other hand, SOLVEQ/CHIM-XPT accurately predicted oversaturation for wells known to deposit calcite scales, as well as undersaturation for wells having no calcite blockages.

Dacillo, et. al. (2008) in an internal EDC report indicated in a review of various geochemical programs, i.e. WATCH and SOLVEQ/CHILLER (predecessor of SOLVEQ/CHIM-XPT), that the differences may lie in the activity of calcium (Ca^{2+}) in solution. Since WATCH has less calcium-bearing species in its calculation relative to SOLVEQ/CHIM-XPT, it will inherently calculate higher calcium availability, thus resulting in higher calcite saturation values. This phenomenon was similarly expressed by Reed (pers. com). Dacillo, et. al. further opined that the calculation of saturation index for calcite in WATCH can also be due to the type of water which became the basis for the development of the software, i.e. fitted to the low-Cl system (<1000 ppm) of Iceland geothermal systems. The absence of CaCl complexes, i.e. $CaCl_2^o$, and $CaCl^+$ may explain these discrepancies.

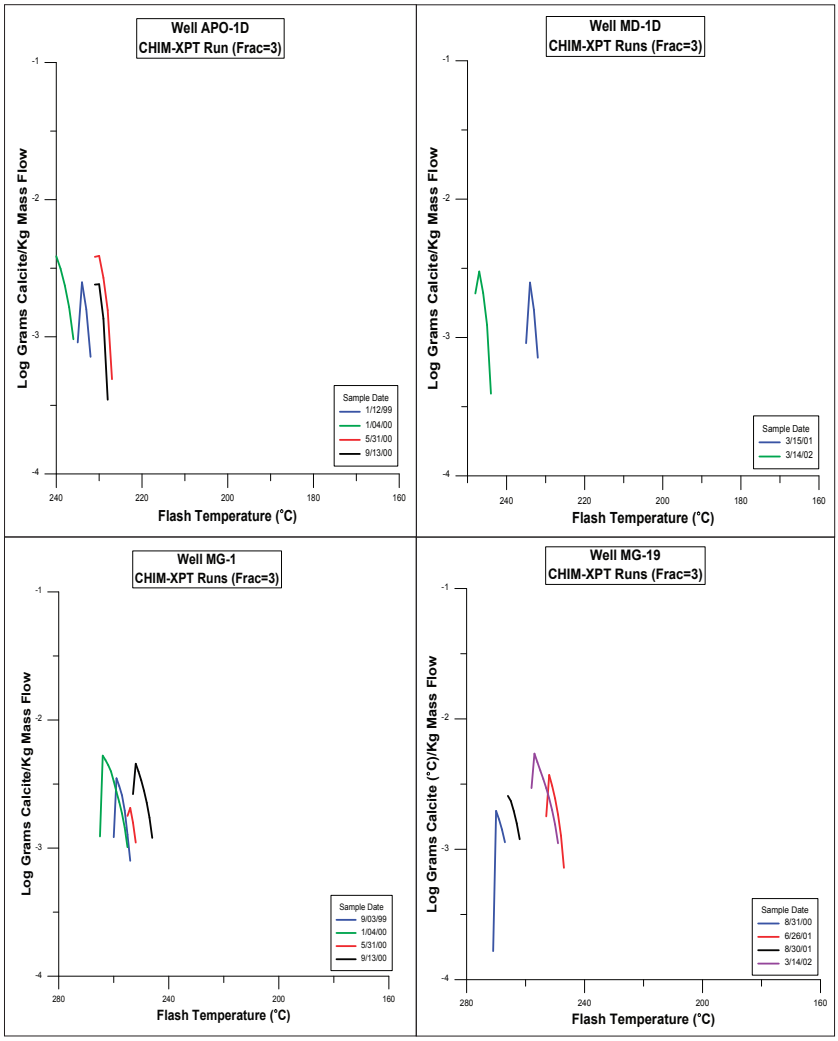

Figure 4. CHIM-XPT Graphs Showing Log grams of Calcite at the Flash Temperature at frac=3.

Table 3. Summary of Calculated SI Values.

Well Name	Calcite SI (Log Q/K)		Calcite (Log Grams/Kg	
			Chim-XPT	
	Watch V2.1	Watch V2.4	Frac 0	Frac 3
MG1	0.001 to 0.563	0.252-1.014	-1.61 to -4.13	-2.34 to -3.10
MG19	-0.142 to 0.912	0.503 to 1.43	-1.72 to -4.03	-2.40 to -3.78
503	-0.564 to 0.145	-0.063 to 0.575	Nil	Nil
APO1D	-0.016 to 0.75	0.40 to 1.098	-2.04 to -3.81	-2.41 to -3.31
MD1D	-0.004 to 1.082	1.335 to 1.611	-2.20 to -3.98	-2.52 to -3.41
APO3D	-2.46 to -0.203	-1.008 to -0.003	Nil	Nil

Conclusions

Both WATCH and CHIM-XPT are useful tools in assessing the calcite scaling tendencies of wells. Comparing both tools, WATCH may sometimes overestimate the calcite scaling potential relative to CHIM-XPT, based on the calibration runs conducted using both softwares. Moreover, SOLVEQ/CHIM-XPT is deemed a better tool for simulating actual conditions as the fluids ascend in the wellbore. Both softwares are mere tools for assessing the calcite scaling potential of wells and should not be used for pre-empting installation of calcite inhibition systems. The mitigating measures that may be put in place will depend on the actual rate of mineral deposition and economic assessment of availing only mechanical workover to clear the calcite blockage and/or installing inhibition systems.

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