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MG9D Acid Well Utilization: Revisiting the Past and Harnessing Its Future

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ABSTRACT

After being drilled in 1993, the prospect of using well MG9D for production became uncertain due to the low-pH and highly corrosive nature of its discharged fluids. Through the years, the experiences of other geothermal fields (like in Costa Rica) on acid well utilization and the research and pilot testing conducted on MG9D reinforced the current strategy of adapting a neutralization technology for the MG9D acid well utilization. The first downhole injection neutralization technology to be installed by EDC, the project is set to prove the effectiveness of the industrial application and hence serve as a prototype for future acid wells utilization requiring neutralization technology.

This paper presents a re-assessment of the previous chemistry simulations performed on acid well MG9D and attempts to identify potential problems that may arise with its utilization. Updated chemistry obtained from recent discharges were used to simulate mixing of MG9D in-situ fluid and NaOH solution based on newly acquired flash point and caustic soda injection depth data. The results were evaluated for consistency with previously specified dosing requirements. Chemistries of the resulting mixtures were also re-examined for saturation indices trends of the minerals anhydrite, calcite, amorphous silica and minnesotaite. Also, stratigraphy and structural permeability showed close proximity of MG9D to injection well MG21D at < 500m separation making the prospect of brine returns affecting MG9D utilization more pronounced. For this reason, mixing of MG9D in-situ fluids with MG21D injected brine chemistry was also modeled to investigate possible alterations in MG9D's fluid chemistry that may affect the operation of the acid well utilization system. The initial commissioning performance of the industrial dosing system is also presented.

1. BACKGROUND

The Mahanagdong Geothermal Field (MGF) has four wells (i.e. MG9D, MG15D, MG20D and MG21D) drilled in the northern sector that have acid Cl-SO_4 type of discharge fluids (Fig.1), with pH levels ranging from 2.9-3.4 (Villa et al., 2000). In the past, these inherent acidic and corrosive fluids deterred utilization of the wells for production due to the foreseen damages to existing surface facilities. Commercial operation of acid wells, however, is viable through the use of neutralization technology. This strategy was successfully demonstrated in acid-sulfate wells BAR-08 of Chevron, Philippines (Gardner et. al., 2001) and PGM-19 of Miravelles, Costa Rica (Rodriguez, 2006) where each gave additional capability to plant generation.

In the Mahanagdong sector, a major concern for production is its declining steam supply due to calcite deposition in wellbores and inflow of cooler fluids (i.e. brine injection returns and groundwater inflow) that are affecting the performance of its production wells. One of the solutions forwarded to increase steam availability is to test a new technology and apply corrosion control in the acid wells for use in production. Well MG9D was specifically chosen to serve as prototype because it is within the vicinity of the field's upflow and is proximate to the production sector that can easily be cut-in to the fluid collection and reinjection system (FCRS). Fluid acidity in MG9D is primarily attributed to the weak acid HSO_4^- that readily dissociates to H^+ and SO_4^{2-} at lower temperatures, thereby resulting to a reduced fluid pH at the surface (Parilla, et. al., 1997).

1.1 Previous Works

A pilot testing of the neutralization technology in MG9D was conducted in 1999. Using 2% NaOH solution injected at a depth of 20 m through a 1" sucker rod at maximum pump stroke, increase in fluid pH and reduction of the corrosion rates by as much as 90% were successfully attained. These strengthened EDC's thrust to integrate the plan of applying an Acid Inhibition System (AIS) for the MG9D acid well utilization and invited more scholastic efforts to make in depth investigations on its application in order to identify the exact chemical and physical parameters necessary for the set-up.

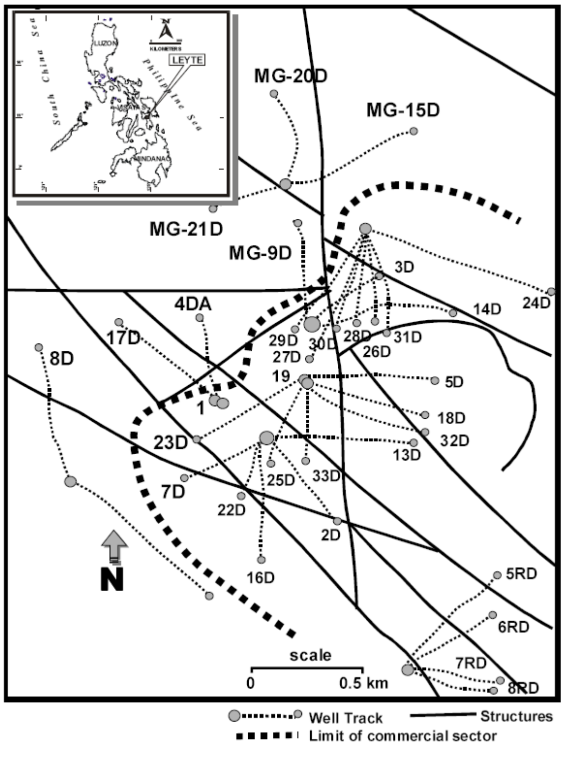

Figure 1: Well track map of Mahanagdong Geothermal field showing acid wells MG9D, MG15D, MG20D and MG21D.

In 2001, Sanchez et al. performed chemistry simulations in MG9D using WATCH (Arnorsson et al., 1982) and PHREEQC (Parkhurst et al., 1980) softwares to evaluate the effects of (HSO_4^-/SO_4^{2-}) buffer to NaOH injection. Results showed that by setting the injection point at 950-1253 mMD at 0.9-1.0% mix of 0.25 m NaOH, MG9D's fluid pH will increase enough to overcome the maximum effectiveness of the (HSO_4^-/SO_4^{2-}) buffer that controls pH.

In 2004, well MG9D was re-discharged to gather updated output, wellhead pressure and fluid chemistry. The well proved that it can be operated at commercial wellhead pressure (WHP) of 1.2 MPag. Updated fluid chemistries were used as basis for flash point simulation, caustic soda dosing rate computations and other dosing specifications. The final dosing schematics and pH modification set-up are shown in Table 1 and Figure 1, respectively. The caustic soda dosing point was set below the flash point depth of ~1200 mMD (based on wellbore simulation), to ensure complete liquid-liquid mixing of NaOH and MG9D in-situ fluids.

Table 1: Well MG9D Final Dosing Scheme.

MG9D FINAL DOSING SCHEME	
INJECTION POINT:	1400 mMD
TARGET INCREASE IN FLUID pH:	4.5 - 5.0
WELL TOTAL MASS FLOW:	59 kg/s
DOSING RATE:	162 li/hr
NaOH CONCENTRATION:	5%
INJECTION PRESSURE:	900 psig (minimun of 700 psig)
TUBING LENGTH / DIAMETER:	1500 m / 0.5" Sancro 8 tubing

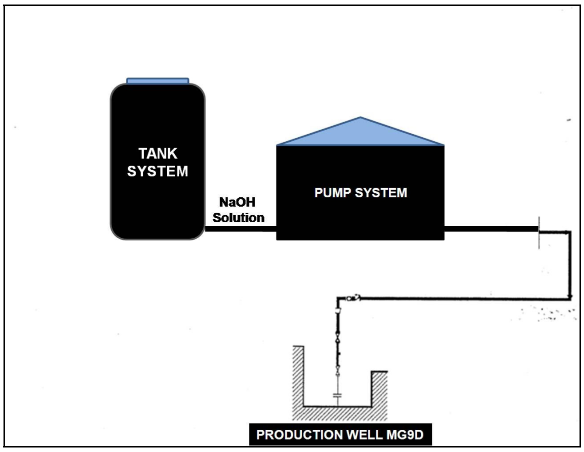

Figure 2: Simplified Schematic Diagram of the MG9D pH Modification Set-up.

With the commissioning of the neutralization technology in MG9D, recognizing potential problems that may arise during its operation is vital. Thus, another simulation using WATCH, PHREEQC and SOLVEQ (Reed and Spycher, 1984) softwares was performed in 2008 to assess the scaling potential of certain minerals within the surface facilities once dosing in MG9D begins. Focus was given to the mineral minnesotaite (amorphous iron silicate) which was found to have caused severe scaling inside the two-phase lines and separator vessels in Miravalles Geothermal Field in Costa Rica (Rodriguez, 2006). Based on this study of Rodriguez, minnesotaite scaling occurred massively in areas where caustic soda dosed and neutral fluids from neutral production wells mixed. In the case of MG9D, results of the simulation showed that resulting mixtures of caustic soda dosed MG9D fluid and neutral fluids of existing nearby wells in Mahanagdong-A will be supersaturated in minnesotaite at the two-phase header, separator vessels and flash vessels (Belas-Dacillo and Angcoy, 2008).

1.2 Recent Activities

Well MG9D underwent workover in 2008 for two main objectives: (1) clear the wellbore of the blockages tagged in February 2007 and May 2007 at 1200 mMD and (2) address the blockage or possible liner break at ~1460 mMD that was tagged in 1999 and 2003. Three downhole viewer runs were performed during the workover to check these blockages and evaluate the over-all integrity of MG9D wellbore. Milling operations were performed to clear the wellbore of obstructions and metal fragments were fished-out using a 5" magnet assembly. The 9-5/8" casing was relined with 7" casing to seal off the casing breaks, and a 5" slotted liner was run-in and set at 1509.6 mMD.

Water loss survey suggests that zones below 1509 mMD are still accepting fluids (Fig. 3). The temperature profile shows increasing bottom temperature from 221°C to 230°C suggesting that MG9D is continuously heating-up, although a reversal in temperature is observed from 1300 mMD to 1400 mMD. The well has a stable water level at 600 mMD as shown in the pressure profile. Elevated pressure of 2.5 MPag was observed during the 5 Day Shut survey, attributed to gas accumulation through time inside MG9D.

Based on the 12.5 li/s MPa injectivity index that was measured, MG9D was estimated to give an output of about 1 MW at WHP of 1.25MPag. A 2nd injectivity measurement done recorded an injectivity index of 18.2 li/s-MPa, comparable to post-1994 workover value of 19 li/s-MPa. This, was used in simulating wellbore conditions to predict MG9D output during discharge and determine the flash point. Two cases were evaluated and results are summarized in Table 2. Case 1 at ΔP=1.0MPag shows that the acid inhibition system (AIS) tubing can be set with ~100m clearance from flash point (1405.2 mMD) within the relined section if well's downhole enthalpy (H) will not exceed 1125 kJ/kg. Also, flashing would still occur until downhole enthalpy is 1160kJ/kg (flash point depth=1490 mMD). However, MG9D will only develop commercial WHP with an estimated output of 1.71 MW at the main plant if downhole enthalpy is 1175kJ/kg. On the other hand, Case 2 at ΔP=1.5MPag shows that the AIS tubing can be set with just ~80m clearance from the flash point (1430 mMD) at downhole enthalpy of 1100kJ/kg. Furthermore, flashing within the re-lined section is predicted to occur at downhole enthalpy below 1150kJ/kg (flash point depth=1484 mMD), but commercial WHP for TCP utilization will not be attained even at a downhole enthalpy of 1200kJ/kg.

Well MG9D was discharged three times via air compression in December 2008. Physical and chemical data collected during discharge are presented in Figures 4 and 5, respectively. The pH trends show that MG9D is acidic with pH levels ranging from 3.0 to 4.0 at the surface, still comparable to the pH of MG9D discharge fluids collected in the past. The current reservoir temperature of 290°C is also consistent with 1994 and 1995 data. Lower Tqtz in 1999 and 2004 however, are attributed to MG9D being utilized as a brine and condensate well from 1999 to 2003. The similarity in the fluid source in these two periods is supported by the uniformity observed in the boron levels of the discharged fluids. Historically, MG9D is one of the wells in Mahanagdong that is known to have elevated Tqtz and chloride levels because it is located within the upflow of the field. At present however, discharged fluid chemistry of MG9D still shows reduced chloride indicating that it has not been totally cleared from fluids used during workover. Iron levels in the present discharge are also consistent with that of the 1995 discharge after mechanical workover, suggesting that the elevated Fe content observed in MG9D's discharged fluid of 1994, 1999 and 2004 was due to corroded casing.

2. CHEMISTRY SIMULATION

2.1 Description of the Present Simulation Work

With the commissioning of the neutralization technology in MG9D, it is the objective of this work to evaluate potential problems within MG9D wellbore that may arise due to the utilization of the caustic soda-dosed fluid of MG9D. Specifically, pH and mineral saturation index trends are simulated using the well's updated discharge fluid chemistry and the findings of the recent flash point simulation from reservoir engineering data. Results of the simulation and of previous studies, will be validated using the actual physical and chemical data that will be obtained once the AIS in MG9D becomes operational. Mixing of MG9D in-situ fluids with MG21D injected brine chemistry will also be modeled to investigate possible alterations in MG9D's fluid chemistry that may affect the operation of the acid well utilization system. Based on stratigraphy and structural permeability, well MG9D is in close proximity to injection well MG21D at < 500m separation making the prospect of brine returns affecting MG9D utilization more pronounced. Geochemical compatibility of MG21D brine and MG9D fluid chemistries were evaluated from mixing simulations using the geochemical softwares WATCH (Arnorsson et al., 1982) and PHREEQC (Parkhurst et al., 1980). The simulated chemistries were evaluated for saturation indices trends of the minerals anhydrite, calcite, amorphous silica and minnesotaite.

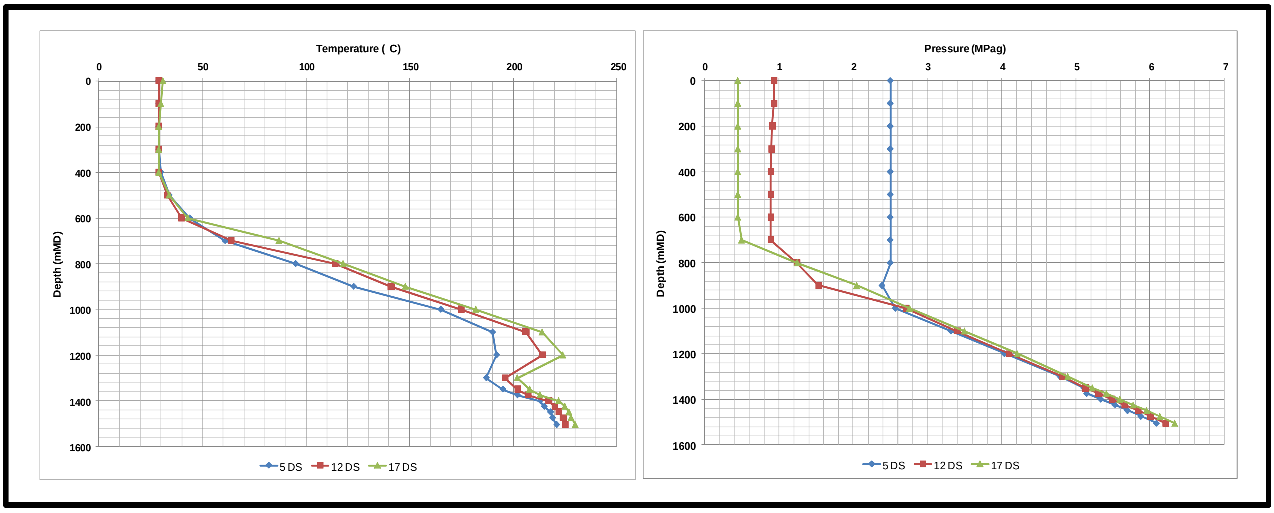

Figure 3: Results of KT/KP Survey in Well MG9D.

Table 2: Summary of Well MG9D Post Workover/Relining Simulation Results.

CASE 1: ΔP (P_{res} - $P_{flowing}$) = 1.0 Mpa, Mass Flow = 18.2 kg/s					
Downhole Condition (@ 1509 mMD)			Flash Point	Wellhead Condition	Main Plant
Pressure	Temperature	Enthalpy	Depth	Pressure	Ouput
(MPag)	(^{o}C)	(kJ/kg)	(mMD)	(MPag)	(MWe)
5.09	258.0	1125	1405.2	0.87	-
5.09	261.0	1140	1440.5	0.96	-
5.09	263.0	1150	1464.9	1.02	-
5.09	265.0	1160	1490.0	1.08	-
5.09	266.5	1175	-	1.17	1.71
5.09	266.5	1200	-	1.32	1.79
CASE 2: ΔP (P_{res} - $P_{flowing}$) = 1.5 Mpa, Mass Flow = 27.3 kg/s					
Downhole Condition (@ 1509 mMD)			Flash Point	Wellhead Condition	Main Plant
Pressure	Temperature	Enthalpy	Depth	Pressure	Ouput
(MPag)	(^{o}C)	(kJ/kg)	(mMD)	(MPag)	(MWe)
4.59	252.9	1100	1429.75	0.43	-
4.59	258.0	1125	1484.4	0.57	-
4.59	260.2	1150	-	0.72	-
4.59	260.2	1200	-	0.94	-

Date	Time	WHP (Mpag)	Weirflow (kg/s)	Initial WHP Prior to VD After Air Compression
04-Dec-08	1140H	0.13	12.26	5.3MPag
	1207H	0.15	13.42	
06-Dec-08	1135H	0.18	13.42	5.6MPag
	1155H	0.18	13.66	
11-Dec-08	1610H	0.2	14.63	5.8MPag
	1920H	0.18	14.63	

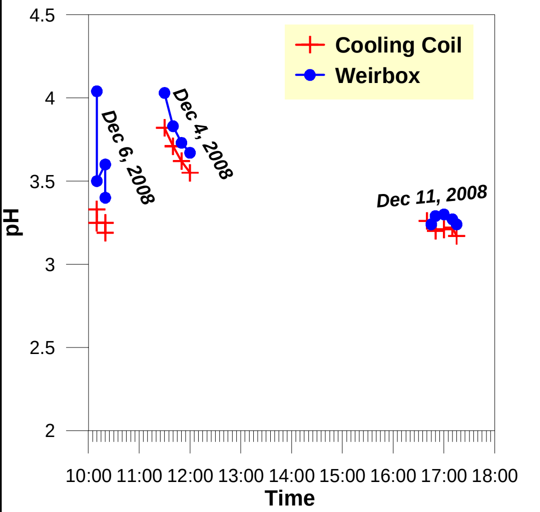

Figure 4: Physical Data and Fluid pH Trends of Well MG9D.

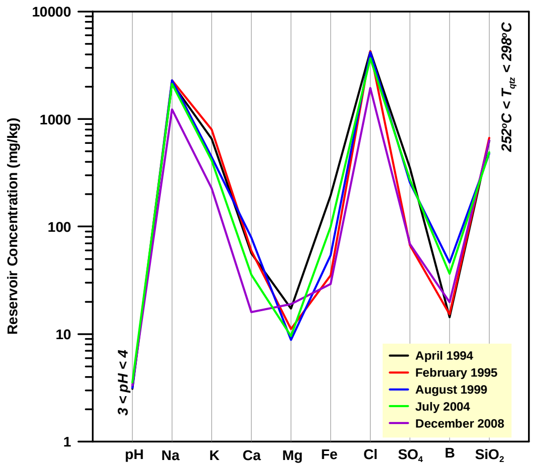

Figure 5: Schoeller Diagram of MG9D Fluid Chemistry.

2.2 Methodology

2.2.1 Data Selection

The simulation is divided into two parts. The first part aims to model the behavior of MG9D fluid within the wellbore once complete mixing of MG9D in-situ fluid and 5% v/v of 50% NaOH is attained at the approximated setting depth. For this purpose, the estimated flash point depth of 1405 mMD in Case 1 of the post MG9D workover/re-lining simulation was utilized. The second part on the other hand, focuses on simulating MG9D in-situ fluid and MG21D brine mixing. The MG9D discharge fluid chemistry employed throughout the simulation was that of actual samples collected using the webre separator. Although commercial WHP was not attained during the recent discharge attempts, the analyzed MG9D discharge fluid samples have good ionic balance (<5% difference) and is assumed to be acceptable representatives of the fluid. Consequently, MGB3 brine chemistry of August 2008 was utilized to represent MG21D brine.

2.2.2 Part 1: Assessment of Well MG9D Fluids

Through the aide of WATCH software, MG9D discharge fluid chemistry as sampled were recalculated to reservoir condition and allowed to adiabatically flash (at 100% degassing) to flowing temperatures to simulate the discharging/flowing condition of well MG9D and obtain pH trends as well as saturation indices for the minerals calcite, anhydrite, amorphous silica and minnesotaite along the wellbore.

Both WATCH and PHREEQC were used to simulate caustic soda dosing of MG9D fluids. Injection at depths 1505 mMD and 1400 mMD were modeled in order to compare resulting wellbore conditions at the current calculated AIS tubing setting depths to the previously recommended depth of injection. Based on the 2008 simulated flash point depth of 1405 mMD (Table 2), the calculated AIS tubing setting depth is at 1505 mMD. The simulated downhole temperature of 258°C at discharge enthalpy of 1125 kJ/kg (Table 2) was used as corresponding temperature at this depth since this is almost near the maximum cleared depth of 1509 mMD. At a depth of 1400 mMD (~250°C), complete liquid-liquid mixing at saturated condition was assumed to simulate mixing at the flash point. Chemistries of the resulting mixtures were then adiabatically flashed to flowing temperature using WATCH to assess the behavior of caustic soda dosed MG9D fluid within the wellbore.

2.2.3 Part 2: Mixing Simulation

The second part of the simulation utilizes PHREEQC extensively in the mixing process. Mixing models were performed using the MG9D reservoir chemistry in Part 2 and MGB3 brine chemistry at line condition (Table 3). The resulting chemistries of the mixtures were also adiabatically flashed to flowing temperature using WATCH to speciate the mixtures and predict pH and saturation index trends of the minerals calcite, anhydrite, amorphous silica and minnesotaite within the wellbore.

Table 3: Summary of Mixtures Simulated with PHREEQC.

MIX-1	90% Untreated MG9D Fluid +10% MGB3 Brine (most manageable scenario)
MIX-2	70% Untreated MG9D Fluid + 30% MGB3 Brine
MIX-3	50% Untreated MG9D Fluid + 50% MGB3 Brine
MIX-4	30% Untreated MG9D Fluid + 70& MGB3 Brine
MIX-5	10% Untreated MG9D Fluid + 90% MGB3 Brine (worst case scenario)

3. RESULTS AND DISCUSSION

3.1 MG9D Wellbore Conditions

Figure 6 presents the pH and mineral saturation index trends for the minerals calcite, anhydrite, amorphous silica and minnesotaite of the untreated MG9D fluid. The neutral pH range within the wellbore temperature of 300°C and 180°C is calculated to extend from 5.7 to 6.2 (Reed and Spycher, 1990). Relative to these values, MG9D untreated fluid is acidic (4.4 ≤ pH ≤ 3.8) within the wellbore and starts to go below the 4.5 pH value limit (for corrosion to be within manageable levels) at Tqtz of 260°C. MG9D downhole temperature at its maximum cleared depth (MCD) of 1509 mMD ranges from 258°C to 266°C (Table 2). At the current well profile, MG9D will be highly susceptible to corrosion from the bottom of its liner to the wellhead. In contrast to the neutral pH plot, MG9D pH trend is directly proportional to temperature suggesting that at temperatures lower than that at the wellhead, corrosion will be more pronounced as

MG9D fluid will be more acidic. In terms of mineral saturation, MG9D fluid is saturated with anhydrite and amorphous silica within the wellbore and undersaturated in calcite. Undersaturation to minnesotaite is also demonstrated but reaches saturation at 250°C to 220°C. Results indicate that in its untreated state, scaling potential within the wellbore of MG9D fluids with respect to the mentioned minerals are low.

The results of the NaOH and MG9D in-situ fluid mixing simulation is presented in Figures 7 and 8. Untreated MG9D fluid has pH values of 4.5 and 4.4 at 1505 mMD and 1400 mMD, respectively. Injecting NaOH at 1505 mMD (T=258°C) will cause MG9D fluid pH to rise to ~5.2 but will barely reach the pH of 4.5 as it flashes towards the wellhead (T=188°). Consequently, injecting caustic soda at 1400 mMD (T= 250°C) will elevate MG9D fluid pH to 5.5 and will stay within this level until it reaches the surface. The corresponding pKa values of HSO_4^- at 258°C and 250°C are 5.4 and 5.3 respectively (see Arnorsson et al., 1982). Previous simulations by Sanchez (2001) demonstrated that caustic soda dosed MG9D fluid should have resulting pH values greater than pKa so that the acid inhibition system will be effective. This explains why the simulated dosing at injection point of 1400 mMD proved to be more effective at 1505 mMD. Results also show that pH elevation is influenced more by the pKa than by the dosing rate.

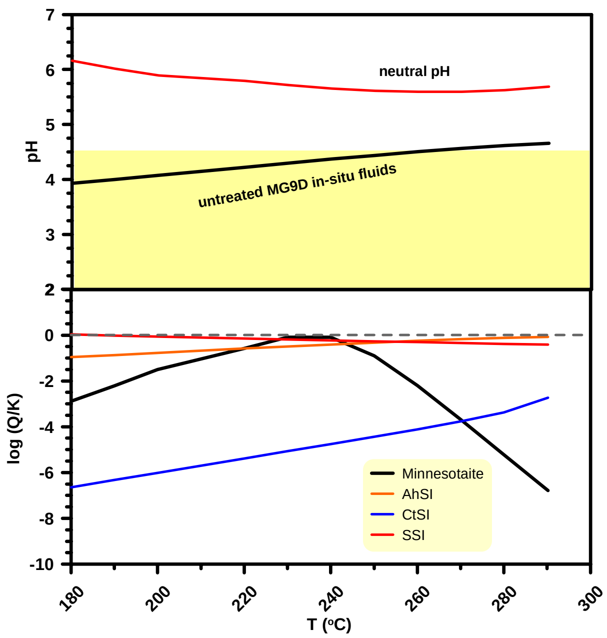

Figure 6: Untreated MG9D pH and Mineral Saturation Index Trends.

The caustic soda dosed fluid of MG9D is undersaturated (log (Q/K) < 0) with calcite within the wellbore. It is undersaturated with amorphous silica at depths but tends to reach saturation as it approaches the wellhead (T=188°C). In contrast, addition of NaOH makes the resulting MG9D fluids saturated (log (Q/K) ranging from 0 to 0.6) with anhydrite at depths and undersaturated as it boils towards the surface. The increased scaling potential is more pronounced when caustic soda is injected at 1505 mMD than at 1400 mMD. Minnesotaite supersaturation (log (Q/K) > 0) within the wellbore is observed in the fluids dosed at both injection depths. However, higher saturation indices ranging from 5 to 8 were observed in MG9D fluids neutralized at 1400 mMD and supersaturation of the fluid was maintained even as it flashes towards the wellhead. When dosed with NaOH at 1505 mMD, minnesotaite saturation indices of the resulting fluid also reached 6.0 but the scaling potential decreases as fluids are adiabatically boiled to lower temperatures. This is because precipitation of minnesotaite is largely dependent on the concentration of H^+. As the fluids become more acidic, the likelihood of minnesotaite to deposit becomes slimmer.

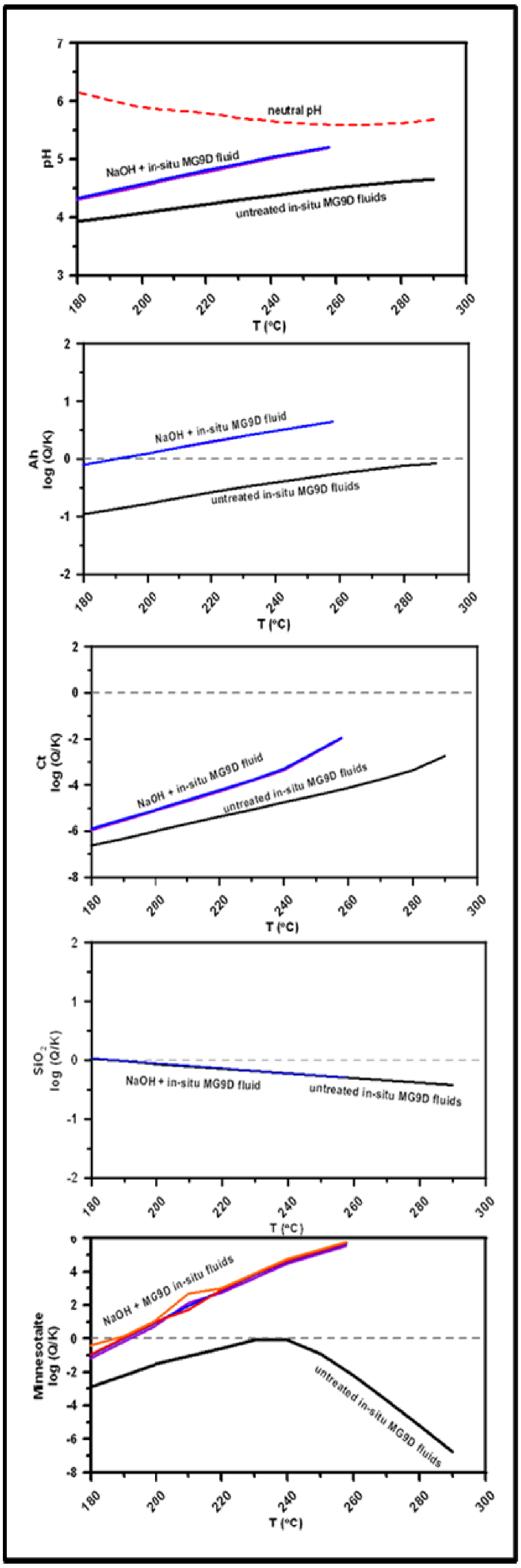

Figure 7: pH and Mineral Saturation Index of (NaOH + In-situ MG9D Fluids) at 1505 mMD (258°C).

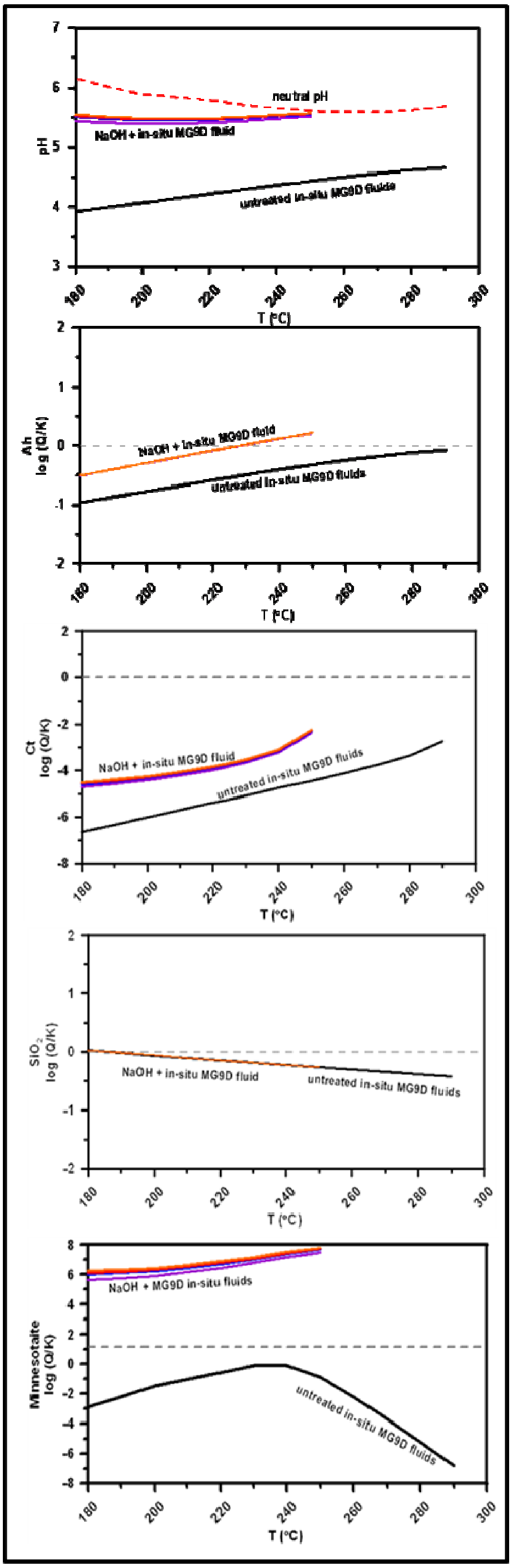

Figure 8: pH and Mineral Saturation Index of (NaOH + In-situ MG9D Fluids) at 1400 mMD (250°C).

3.2 Mixing Simulation

The corresponding neutral pH at 164°C is 5.8 (Reed and Spycher, 1990). Based on MGB3 fluid chemistry, the brine with pH of 6.189 is slightly alkaline at line condition and is undersaturated with the common minerals anhydrite, silica and calcite. Although its fluid is already supersaturated with minnesotaite, no actual scaling in the brine line has yet been documented. In the previous simulation works, minnesotaite saturation index of 6.2 and 9.4 were generated for fluid mixtures at the separator and flash vessel, respectively, but no severe minnesotaite scaling have also been experienced (Belas-Dacillo and Angcoy, 2008).

Table 3 presents a summary of the mixtures simulated with PHREEQC. In general, addition of MGB3 brine will reduce the acidity of the untreated MG9D fluid (Fig. 9). Resulting pH trends for MIX-1 and MIX-2 show that the mixtures are still acidic within the wellbore but are still higher (generally above 4.5) in comparison to the pH of untreated MG9D fluid. Like MG9D, both mixtures also exhibited direct proportionality of fluid pH to temperature. The resulting pH of the mixtures becomes more alkaline within the wellbore as more brine is mixed with MG9D fluid, and pH becomes inversely proportional to temperature. No significant thermal deterioration below the commercial temperature of 220°C is demonstrated until 70% of MGB3 brine is mixed with 30% of MG9D fluid (MIX-3).

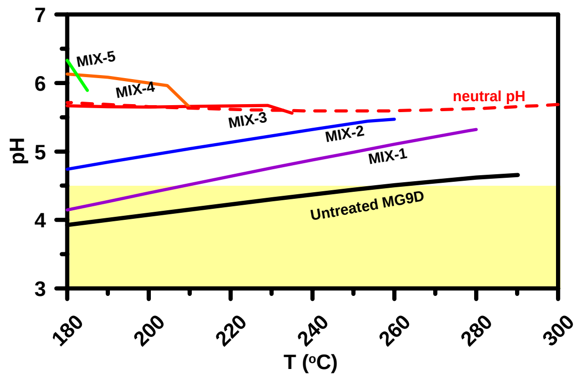

Figure 9: pH Trends if Untreated Well MG9D Fluids and MGB3 Brine Mixtures.

Results of the mineral saturation evaluation of the mixtures are illustrated in Figure 10. All mixtures are undersaturated (log (Q/K) < 0) with calcite and amorphous silica, although saturation in the latter is achieved at the wellhead. Supersaturation with anhydrite within the wellbore is observed only in MIX-1, MIX-2 and MIX-3, but supersaturation with minnesotaite is observed in all mixtures. Minnesotaite supersaturation increases proportionally with respect to Fe and SiO_2 concentrations but declines when more lower-pH MG9D is added in the mixture primarily due to the greater influence of H^+ ions in the mineral's dissolution process. Hence, supersaturation with minnesotaite also increases in mixtures where MGB3 brine is present in greater proportion such as MIX-4 and MIX-5. Addition of NaOH will simply increase the scaling potential of this mineral as H^+ concentration will be further depleted.

4. INITIAL COMMISIONING PERFORMANCE

Well MG9D was discharged via air compression in December 2008. The main objectives of the discharge was to run-in the Acid Inhibition System (AIS) tubing to the programmed setting depth of 1400 mMD and commence NaOH dosing into the wellbore. Secondary to this were the collection of physical data to validate the well's output and the gathering of fluid samples for chemistry updating. The fluid samples for pH analysis were collected at the weirbox and using cooling coil while simultaneously conducting on-line pH monitoring. The pH levels recorded were between 3.0 to 4.0.

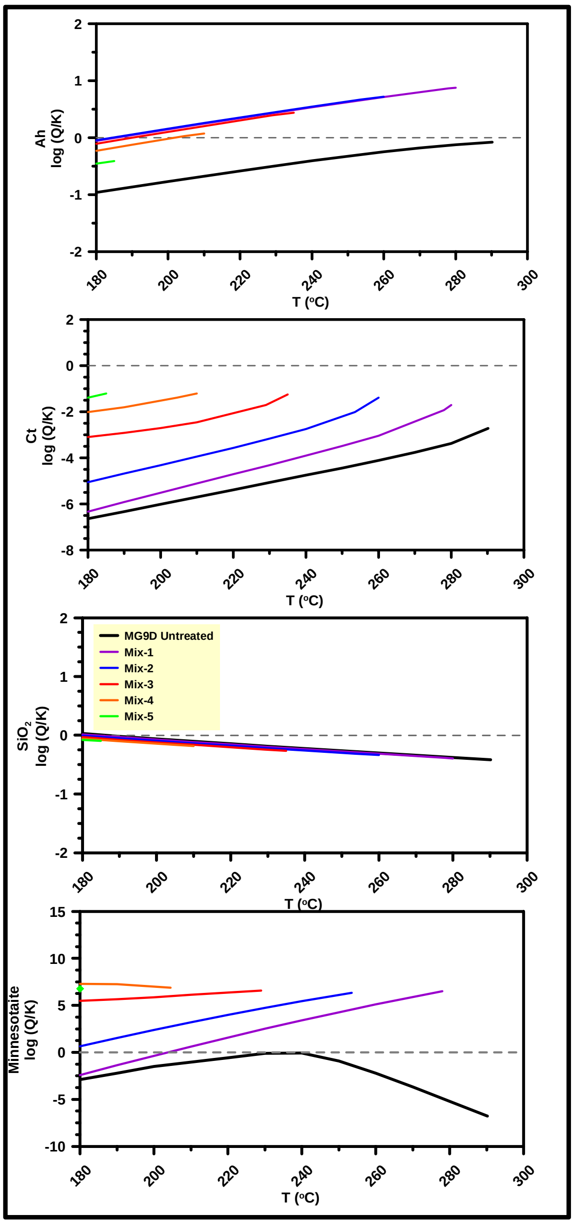

Figure 10: Mineral Saturation Indices of Untreated MG9D and MGB3 Brine Mixtures.

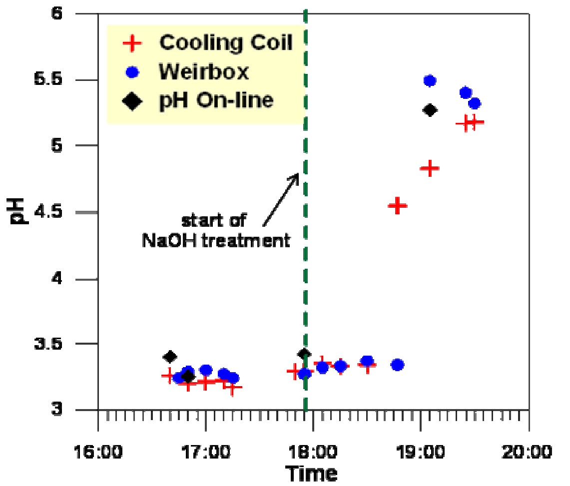

Figure 11: pH Trends of Caustic Soda Dosed Well MG9D Fluids.

Well MG9D was vertically discharged and diverted to horizontal discharge three times but did not attain commercial WHP and thus no commercial output was measured. Run-in of the AIS tubing was attempted in the third discharge.

At a pump rate of 100LPH, pH level of MG9D remained relatively constant at ~3.3 but eventually rose to ~5 after pump rate was increased to 200LPH. However, run-in of the AIS tubing was aborted after it failed to pass through 386 mMD due to a mechanical obstruction, later viewed as casing break through the downhole viewer (DHV). Nevertheless, increase in MG9D's fluid pH by NaOH dosing was successfully demonstrated despite failure to set the AIS tubing at 1400 mMD (Fig. 11).

5. CONCLUSIONS

Chemistry simulation of MG9D wellbore conditions using the updated MG9D fluid chemistry and MGB3 brine chemistry with the aid of WATCH and PHREEQC yielded the following predictions and potential problems anticipated:

a. The current chemistry of MG9D discharged fluid is still acidic with pH ranging from 3.0 to 4.0 at the surface. At wellbore conditions, MG9D fluid is also acidic with pH < 4.5 at Tqtz ≤ 260°C. The simulated temperature at the bottom of liner (1509 mMD) ranges from 258°C to 266°C. Hence, corrosion is predicted to be pronounced from bottom of liner to wellhead.

b. The untreated MG9D discharged fluid is undersaturated with calcite and slightly saturated with anhydrite and amorphous silica within the wellbore. Undersaturation to minnesotaite is also observed except at 250°C≤ T ≤ 220°C where fluid chemistry is slightly saturated. Therefore, scaling occurrence within the wellbore for anhydrite, amorphous silica and minnesotaite is likely without acid inhibition, but scaling potential is to a minimum.

c. The pH of untreated MG9D fluids at the predicted AIS setting depths of 1505 mMD and 1400 mMD is 4.5 and 4.4, respectively. Addition of NaOH at these depths will elevate the fluid pH to 5.2 (at 1505 mMD) and 5.5 (at 1400 mMD). Setting the injection point at 1400 mMD will cause fluid pH to remain fairly constant at 5.5 within the wellbore; fluid pH will drop to 4.5 at the wellhead if AIS tubing is set at 1505 mMD. Therefore, setting the injection point at 1400 mMD will render the AIS more effective in neutralizing MG9D fluids.

d. Caustic soda dosed MG9D fluids within the wellbore are undersaturated with calcite but relatively saturated with anhydrite and amorphous silica. Supersaturation with minnesotaite is observed with log (Q/K) ranging from 5 to 8 in MG9D fluids dosed at 1400 mMD and from 0 to 6 when dosed with NaOH at 1505 mMD. Therefore, mineral scaling due to anhydrite and amorphous silica within MG9D wellbore is likely but will not be as pronounced as that of minnesotaite once MG9D fluids are dosed with NaOH.

e. MG21D brine, represented by MGB3 brine chemistry, has pH of 6.189, above neutral pH of 5.8 at line condition. The injection fluid is undersaturated with anhydrite, amorphous silica and calcite. Supersaturation with minnesotaite is observed but no actual scaling has been documented.

f. Addition of MGB3 brine to untreated MG9D fluid reduces acidity of MG9D within the wellbore. MIX-1 and MIX-2 shows acidic pH trends within the wellbore that is lower than 4.5 and higher than untreated MG9D pH trends.

In both mixtures, pH is directly proportional to temperature and may still yield low pH and corrosive fluids at the surface.

g. MIX-3, MIX-4 and MIX-5 chemistry shows that as more MGB3 brine is added to the untreated MG9D fluid, pH trends become more alkaline at wellbore condition. Also, pH becomes inversely proportional to temperature. Thermal deterioration below the commercial temperature of 220°C starts only when 70% MGB3 brine is added to 30% untreated MG9D fluid. Therefore, brine inflow to MG9D reduces acidity but must be optimized to prevent thermal degradation.

h. Undersaturation with calcite and amorphous silica within the wellbore is observed in all mixtures while anhydrite supersaturation was noted in MIX-1, MIX-2 and MIX-3 only. All mixtures showed supersaturation with minnesotaite. Brine inflow to MG9D will therefore induce scaling of anhydrite and minnesotaite within the wellbore.

6. FUTURE DIRECTIONS

The primary concern in the commissioning of well MG9D's Acid Inhibition System is to test the effectiveness of the technology in addressing corrosion issues involved in the wells utilization. Its success will signify the start of development and expansion pursuits for the company that will not be limited solely to neutral fluid dominated geothermal fields. In LGPF alone, the plan is to put additional acid inhibition systems to acid well MG15D so that this too can be utilized for production. The idea of converting acidic injection wells MG21D and MG20D into production wells is now also being contemplated. The neutralization technology is likewise set to be tested in previously explored geothermal areas that were plugged and abandoned pending new technological breakthroughs in handling acid wells.

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