Mechanism of Calcium Carbonate Scaling in Mahanagdong Geothermal Field, Leyte, Philippines

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ABSTRACT

Calcite scale deposition is one of the major causes of the decline in output of production wells in Mahanagdong – A sector. Analysis of the chemistry of MG-1, MG-7D, MG-19 and MG-23D indicate that their reservoir fluids are saturated with calcite. Flashing of these fluids specifically in MG-7D and MG-19 leads to supersaturation and thus calcite precipitation. The same mechanism is seen at MG-1 and MG-23D; however, the inflow of cooler fluids apparently suppresses further calcite scale formation. Blockages caused by calcite scale deposition have influenced the shift in dominant feed zones leading to the decline in massflows.

The WATCH computer program was used to estimate the calcite growth rates and scale thickness of each well. The predicted calcite thickness based on the growth rates indicates that MG-1 will be fully blocked in 5 months due to its smaller casing diameter, MG-23D in 10 months, MG-7D in 11 months and MG-19 in 1 year and 5 months. The predicted calcite thickness approximates actual measured scale thickness.

Introduction

Calcite scale deposition is a major cause of the decline in output of production wells in the Mahanagdong-A sector of the Leyte Geothermal Production Field along with the rapid reservoir pressure drawdown, inflow of cooler fluids and feed sharing (Bolaños, 1998; Dacillo, 1999). This study primarily aims to identify the processes and mechanism of calcite deposition in Mahanagdong-A wells, and to estimate the rate of calcite scale deposition.

Natural State Hydrogeochemical Model

The assessment of baseline chemistry of the Mahanagdong field (Salonga et al., 1996) showed that the parent fluids in Mahanagdong lie beneath well MG-3D, MG-9D and MG-14D characterized by temperatures of 290°C, Cl_{res} (i.e., chloride concentration at reservoir condition based on silica geothermometry) contents from 4000 to 4200 mg/kg and CO_2 contents of around 400 mmole/100 mole H_2O (1.08 wt%) (Figure 1).

The fluids north of the Mahanagdong field, bounded by the Mamban Fault, are acidic in nature with high levels of SO_4 and H_2S in vapor. Cl_{res} and CO_2 range from 3000-4000 mg/kg and from 200-400 mmole/100 moles H_2O respectively. The fluids have temperatures of 260-280°C and the highest Cl/B ratios (>50).

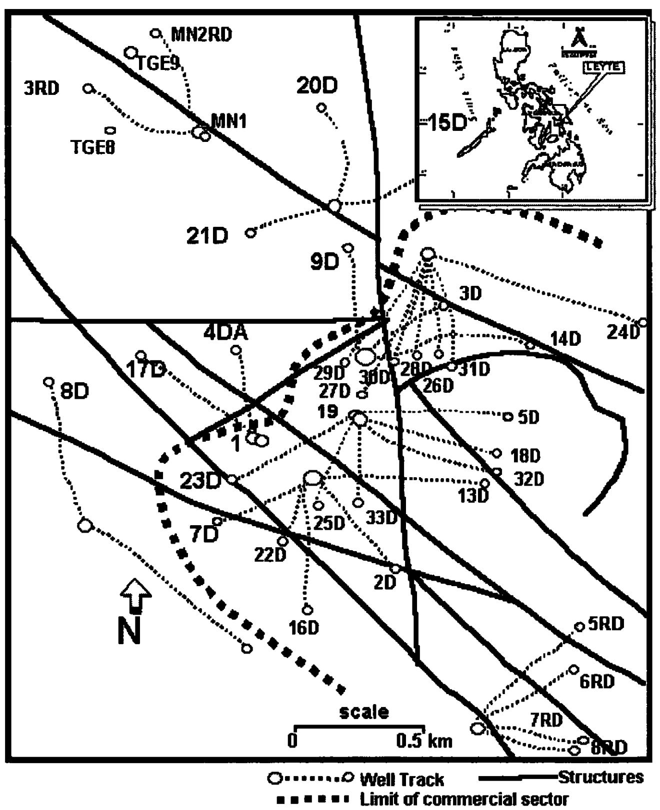

Figure 1. Location map of the Mahanagdong geothermal field, Layte

Wells in the central part of Mahanagdong are characterized by alkaline to neutral pH fluids, with temperatures of 260-280°C and Cl_{res} of 2500-3000 mg/kg. The CO_2 level in the area is below 200 mmole/100 mole H_2O (0.3-0.5 wt%). Cl/B ratios of the wells are homogeneous lying between 21-24. Based on the study on the mineral saturation of the fluids in Mahanagdong, the fluids in the central and southern parts of the field (Figure 2) are inherently saturated with calcite (Martinez, 1997).

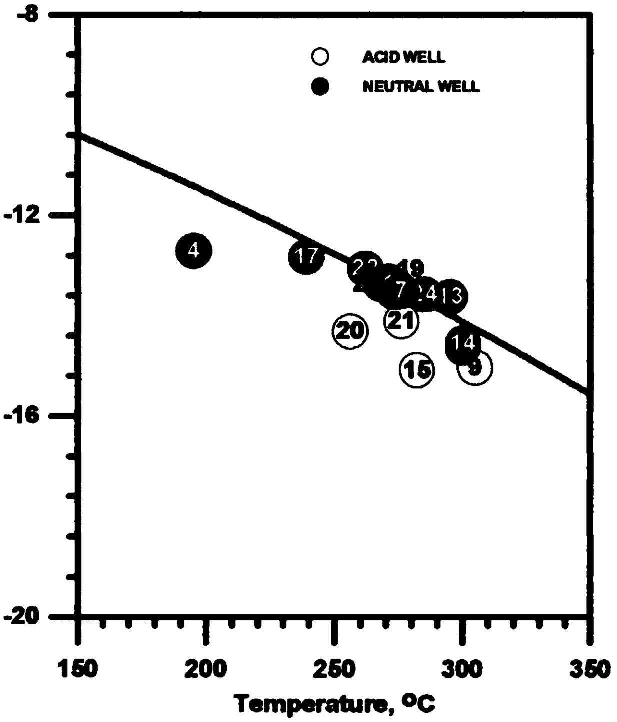

Figure 2. Calcite saturation of Mahanagdong wells at reservoir condition

Wells MG-4DA and MG-17D, which lie in the western part of the field, have temperatures of 240°C, the lowest among the production wells. Their Clres are < 2500 mg/kg. This suggests the presence of cooler and dilute fluids in this part of the field.

Methodology

Four wells from Mahanagdong–A were used for this study namely, well MG-1, MG-7D, MG-19 and MG-23D. However, in this report, only the cases of MG-7D and MG-23D will be presented. These wells were chosen because of a drastic decline in their output, which is believed to be primarily due to calcite scale deposition. Table 1 shows the selected chemistry data of the four wells that correspond to the period of calcite deposition.

Theory of Calcite Deposition

The solubility of calcium carbonate minerals in aqueous solution increases with decreasing temperature and increasing CO_2 partial pressures.

Table 1. Chemistry of selected Mahanagdong wells

Well	MG-1	MG-7D	MG-19	MG-23D
Date	3/5/98	11/3/98	3/12/99	7/7/97
WHP (Mpa)	1.292	1.243	0.942	1.443
SP (Mpa)	1.242	1.213	0.382	1.343
Water Chemistry				
pH @ 25°C	8.13	6.55	7.61	6.7
Li	6.5	7.6	6.7	6.7
Na	1985	2222	1761	1785
K	326	446	551	330
Ca	15	33	35	26
Mg	0.63	1.0	1.06	0.88
Fe	0.11	0.33	0.23	0.13
Cl	3236	3751	2990	3264
SO_4	110	21	63	21.5
HCO_3	166.58	50.3	61	62.2
B	149	57	44	47
NH_3	3.33	1.2	2.06	0
SiO_2	702	725	677	660
H_2S	3.56	1.46	3.3	3.75
CO_2T	55.4	50.1	47.2	59.9
Gas Chemistry				
CO_2	875	895	740	981
H_2S	13.58	13.02	13.94	15.25
NH_3	2.02	1.1	1.48	1.82

Calcite formation is represented by

$$Ca^{+2} + CO_3^{-2} = CaCO_3 \qquad (1)$$

Under normal geothermal conditions however, there is very little aqueous carbonate (CO_3^{2-}) available. Instead, most dissolved carbonate ions are in the form of carbonic acid (H_2CO_3) or bicarbonate (HCO_3^-). As CO_2 gas is lost from a boiling solution, carbonate ions (CO_3^{2-}) are made available and these can react with calcium ions to cause deposition of calcium carbonate.

$$2HCO_3^-{}_{(aq)} = CO_3^{-2}{}_{(aq)} + H_2O + CO_{2\,(gas)}\uparrow \qquad (2)$$

$$Ca^{+2}{}_{(aq)} + 2HCO_3^-{}_{(aq)} = CaCO_3\,(solid) + H_2O + CO_2\,(gas)\uparrow \qquad (3)$$

where $Ksp = [Ca]\,[HCO_3]^2 / [CaCO_3] \cdot f_{CO2}$

Boiling is thus a common cause of calcite scaling in wells. Boiling leads to a strong reduction in CO_2 partial pressure due to transfer of CO_2 in the steam phase that forms. CO_2 has a minimum solubility in water at 160-180°C. According to Arnorsson (1989), degassing of CO_2 leads to an increase in pH and a strong increase in carbonate ion concentration. It is mostly this latter increase that is responsible for making initially saturated geothermal water supersaturated with calcite through boiling. Dissociation of calcium-bearing ion pairs, as water temperatures become lower, also contributes to the extent of supersaturation.

If boiling is adiabatic, the degree of supersaturation reaches a maximum after cooling by some 10-40°C. The magnitude of supersaturation depends only on the extent to which the flashing water is degassed, its salinity and initial temperature. The higher the salinity of the water and the lower its temperature, the higher will be the degree of supersaturation . A study on the solubility of calcite (Ellis, 1963) shows increased calcite solubility at increased concentrations of salt solutions at equal pCO_2 and temperatures. Strongest supersaturation occurs when the temperature of unflashed reservoir water is lowest (i.e. lower CO_2 solubility, temperature-dependent mineral/solute equilibria) and when its ionic strength is highest.

Cases of Calcite Blockages in Mahanagdong Wells

MG-7D

Well MG-7D was the sixth well drilled in the Mahanagdong sector to probe the southwestern extent of the resource. It had a total drilled depth of 2512 mMD but its liner landed at 1826mMD (i.e. Measured Depth refers to actual depth of a deviated well) due to numerous bridges and tight holes. Completion tests detected a major permeable zone at 1450-1550mMD and minor permeable zones at 1600-1675 and 1750-2500 mMD. These were correlated to the intersection of the Central Fault Line and Mahanagdong Fault, respectively.

Blockage History

A decline in total mass flow was observed from TFT results conducted in March 99 to 66.3 kg/s, from 105.3 kg/s in May 98, equivalent to a decline of 39 kg/s in ten months (Figure 3). A 5" GD (i.e. Go-Devil downhole tool for tagging well blockages) tool run in August 98 to check for possible blockages tagged its MCD (Maximum Cleared Depth) at 1837mMD, similar to the previous runs. Downhole temperature measurements however, indicated higher temperatures of 278°C (1400mMD – 1837mMD) compared to 268°C in January 1998. In July 1999, the 6" GD tagged an obstruction at 780mMD while the 5" GD tagged an obstruction at 1019 mMD. Vertical clearing discharge was attempted to rid the bore of blockages. Ejecta samples collected consisted of 50% carbonate scales. These scales are composed of 1.5 mm-thick bands of interlocking fine- to medium-grained (0.25-1.0 mm) calcite and rare aragonite crystals. However, post-VCD (Vertical Clearing Discharge) tagged similar obstructions at almost the same depths. There were apprehensions prior to its planned workover due to its high measured output of 9 MWe after testing last August 5, 1999. Workover operations with the rig were still pursued from August 18 – 21,1999 which encountered mostly soft scales from 1058-1176mMD, within the 7-5/8 liners.

Chemical Trends

Well MG-7D Calcite Saturation Index (CSI) level has shown a gradual decline from February 98 to June 99 ranging from 2.07 to 1.00. Chemical trends during the period showed an increase in Cl_{res} from 2900 to 3000 mg/kg, CO_2TD (Total

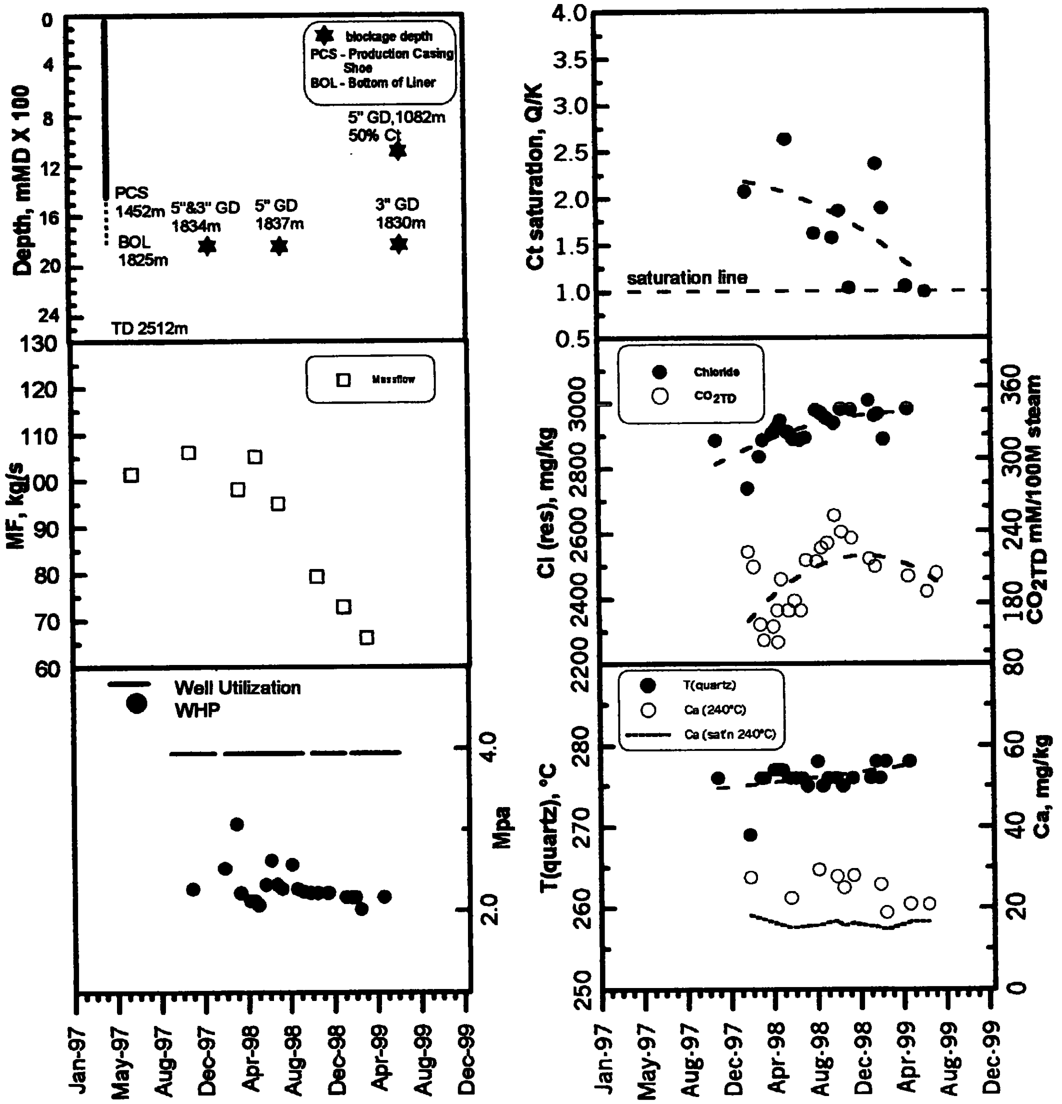

Figure 3. MG-7D Wellbore History and Geochemical Trends

Discharge) values from 160-180 mmole/100 moles to 210-250 mmole/100 moles, and relatively stable Tquartz (i.e. silica geothermometer of Fournier and Potter, 1982) values. The increase in concentrations of the chemical parameters implies localized boiling processes occurring within the wellbore.

Mechanism of Calcite Formation

The decline in total mass flow of MG-7D is most likely due to restrictions caused by calcite deposition in the wellbore. Degassing of the fluids due to localized boiling has initially increased the degree of calcite supersaturation, which accelerated calcite scale deposition. This is apart from naturally occurring process of calcite deposition due to adiabatic boiling as the fluid rises up the well. Enhanced degassing of the fluids is evidenced by the high CSI levels in MG-7D that later dropped to 1.06 - 1.00 after calcite has been deposited in the well.

cal discharge conducted last June 98 recovered ejecta composed of 75% calcite scales, with thickness ranging from 2 to 7mm and mostly interlayered with very thin smectite scales. Another VD (Vertical Discharge) was conducted on June 10,1998, which similarly ejected calcite. Confirmation measurements using the James lip pressure method indicated a massflow of 110 kg/s, which was correlatable to the TFT (Tracer Flow Testing using chemical tracers) results. GD runs (6/9) tagged obstructions at 1469 mMD (6" tool) and at 1543 mMD (3" tool). Both obstructions were improvements from the 3" and 5.5" GD runs conducted in January 98, which tagged obstructions at 1293mMD. The flowing survey conducted 6/9 showed a decline by 7°C at 1300-1500 mMD, compared to the July 96 flowing survey and the well was observed to produce mainly below 1500mMD. The KP (Kuster Pressure) surveys indicated a flashpoint at 1200mMD. In June 11,1998, the well collapsed. It was later revived by two-phase stimulation from MG-19.

MG-23D

Well MG-23D was drilled as a big hole, in-fill production well in pad MG-5D to supply the balance of steam required for the Mahanagdong–A Power Plant. Its objective was to case-off the Lower Mahanagdong Fault and to utilize for production, steam from the Mahanagdong Conjugate-A and Central Fault Line Conjugate faults. Persistent drilling problems such as collapsing formation, tight holes constrained in completing the well as programmed and instead opted to running a two-liner standard diameter casing which reached a depth of 2025mMD from a total depth of 2153mMD. Completion tests identified a major permeable zone at 1400-1500mMD and minor zones at 1550-1650, 1750-1950 and 2000-2025 mMD. The major zone is correlated to the Lower Mahanagdong Fault and minor zones are all attributed to the intersection of the Mahanagdong Conjugate-A Fault.

Blockage History

The well showed significant decline in mass flow from 166.4 kg/s in November 97 to 93.6 kg/s in May 98 (Figure 4). A verti-

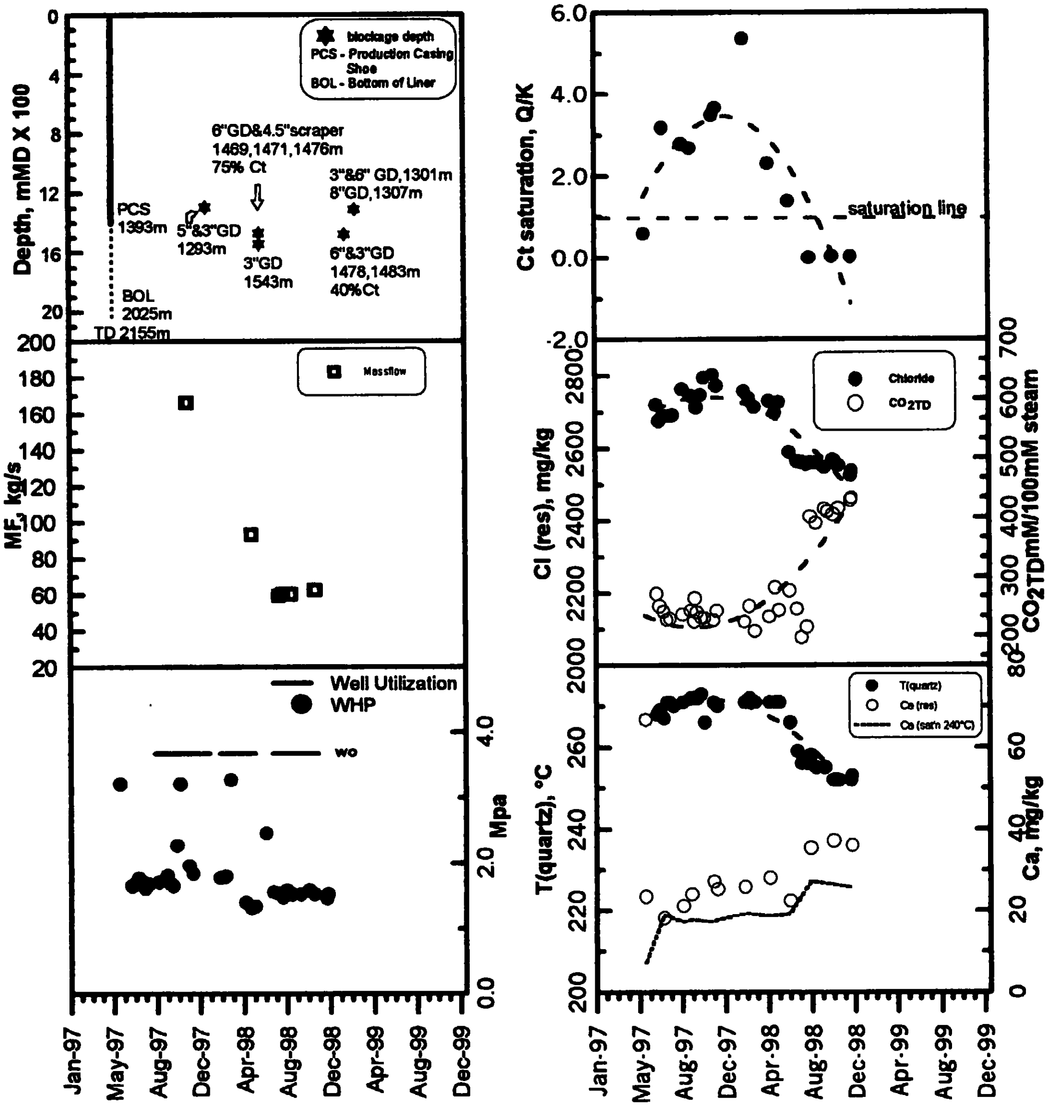

Figure 4. MG-23D Wellbore History and Geochemical Trends

Ejecta samples consisting of calcite were recovered during its VD in June 15, 1998.

In January 1999, GD surveys tagged obstructions at 1478mMD (6" tool) and 1483mMD (3" tool) and recovered samples consisting of euhedral grains of calcite. In February 1999, after the plant shutdown, the well was again discharged by air compression. Ejecta samples consisted mainly of thick carbonate scales (~4 mm thick), comprising of calcite crystals associated with very fine-hair like opaques. However, the well collapsed after the flow was diverted to the silencers. Workover of the well with a rotojet tool was conducted from February 13-17,1999 but the cleared depth only reached 1534mMD after the rotojet got stuck. Post workover tests tagged obstructions at 1307mMD (8" tool) and at 1301mMD (3"& 6" tool). The measured injectivity was 766 l/s-Mpa, which was attributed to the clearing of the wells' permeable zones.

Discharge attempts of the well through air lifting and by air compression conducted on February 26 to March 4,1999, were unsuccessful due to the slow thermal recovery of the well. A continuous decline in well temperature was observed. Downhole surveys conducted in March 99 at 1500 mMD recovered low Cl and high Ca and Mg fluids, characteristic of groundwater. Downhole temperature measurements in April 1999 indicated temperatures of 145°C just below the PCS. Workover operations with the rig were done from June15-19, 1999 with hard scales encountered inside the 9-5/8 liners from 1462-1552mMD and soft scales from 1552-1675mMD. Soft scales were also encountered within the 13-3/8 production casing at 1100-1150 mMD. The well is currently on heat-up after undergoing another workover from August 28 to September 21, 1999 to seal the identified cold water inflow zone at 650 and 1300mMD.

Chemical Trends

Since the start of commissioning the well until May 98, MG-23D was feeding from a zone characterized by fluids with Cl_{res} of 2750-2800 mg/kg, low CO_{2TD} content of 240-270 mmole/100 moles, high T_{quartz} values of 266-273°C and low Ca_{res} concentrations of 25-28 mg/kg. These fluids are characteristic of those channeled through the Mahanagdong Conjugate-A Fault that was intersected at deeper levels. The CSI level during these period was stable ranging from 2.70–3.00.

In July 98, the well discharged a different kind of fluid, characterized by high Ca_{res} of 35-40 mg/kg, low Cl content of 2540-2560 mg/kg, high CO_2TD of 400-430 mmole/100 moles and lower temperatures of 252-259°C. Analysis of the water chemistry show that these fluids are similar to the cool waters sweeping well MG-1 and MG-17D through the Lower Mahanagdong Fault. A drop in CSI levels was also observed from May 98 to December 98 where values ranged from 0.04 -1.38.

Mechanism of Calcite Formation

Well MG-23D was initially producing from the deeper feed, Mahanagdong Conjugate-A characterized by high-temperature, high-chloride, low CO_2 and low Ca fluids. These fluids were supersaturated with calcite and boiling processes occur as these fluids enter the well and rise up to the surface. Calcite deposition due to boiling with time has formed an obstruction in the wellbore, which limited the flow from the deeper feed zone. This shifted the dominant feed from the deeper feed to a shallower feed. Downhole spinner logs detected the inflow of cooler waters from the shallower zones at 650mMD and at 1300mMD, correlatable to the Lower Mahanagdong Fault intercepts. The drop in supersaturation levels which started in May 98, suggests that calcite had deposited in the wellbore.

The decline in steam flow of MG-23D therefore was caused by calcite blockage that influenced the shift of feed zone from dominantly hot saline feed to cooler, less saline feed at 650mMD and at 1300mMD, associated with the Lower Mahanagdong Fault. However, there still is no evidence to link the cooler fluid downflowing in MG-23D to the cooler fluids in MG-1.

Rate of Calcite Growth in Mahanagdong

Application of SOLVEQ and CHILLER programs can actually approximate the kinetics of calcite deposition. However, these programs have not been successful in predicting the rate of deposition in Mahanagdong. In lieu of this program, we devised a simple method by extending the application of WATCH program. Arnorsson based the calculation of theoretical and actual solubility products of calcite in WATCH on the following equations:

$$CaCO_3 \rightarrow Ca^{+2} + CO_3^{-2} \quad (4)$$

With equilibrium solubility equation (K_{eq}) of:

$$K_{eq} = [Ca^{+2}].\ [CO_3^{-2}] \quad (5)$$

From the K_{eq} equation, calcite solubility can be expressed in terms of the concentration of calcium. Therefore:

$$K_{eq} = [Ca^{+2}]^2 = [m_{CaT}\,\gamma_{Ca}]^2$$

$$m_{CaT} = (K_{eq})^{0.5} / \gamma_{Ca} \quad (6)$$

where m_{CaT} is the equilibrium concentration of Ca and γ_{Ca} is the temperature dependent activity coefficient of Ca, which is readily available in WATCH output. Similarly, the actual calcite solubility (Q) can be expressed in terms of actual Ca that participated in reaction (m_{CaA}) as follows:

$$m_{CaA} = Q^{0.5} / \gamma_{Ca} \quad (7)$$

Subtracting m_{CaT} from m_{CaA} gives the amounts of excess Ca^{2+} ions that can form calcite deposits. It is assumed that all these excess Ca^{2+} ions are precipitated as calcium carbonate. Relating the excess Ca in mg/kg with the water flow of the well, in kg/sec, and with the density of calcite (2.713 g/cm^3), the total volume of calcite that will be generated per month can be calculated. We assumed that the flash point inside the well did not have significant movement within the calculation period.

Calculations showed that well MG-23D have the fastest average deposition rate of 0.008 cm^3/s, followed by MG-1 and MG-7D with 0.003 cm^3/s and MG-19 with the slowest rate at 0.001 cm^3/s. MG-23D exhibited the faster deposition rate in spite of having a lower CSI compared to MG-19 because of its higher flow rate of 76 kg/s against MG-19's 37 kg/s.

Dividing the total volume per month by the surface area of the liner size projects the thickness of calcite deposit. Calculations show that well MG-1 will be fully blocked after 5 months while well MG-7D will be fully blocked in a year and five (5) months time. Meanwhile, MG-19 will be totally blocked after eleven (11) months and MG-23D will be blocked after ten (10) months.

The predicted calcite thickness was compared with downhole xy-caliper surveys conducted prior to each well workover. The results are generally in good agreement with the actual downhole measurements.

Concluding Remarks

Chemical trends and the well blockage history indicate that the decline in massflow of wells MG-1, MG-7D, MG-19 and MG-23D is mainly due to calcite deposition. The mechanism by which calcite is precipitated in these wells is through boiling or flashing their initially calcite-saturated fluids. Based on the calculated growth rates, scale cleanout should be done every

5 months for well MG-1

1 year and 5 months for well MG-7D

11 months for well MG-19

10 months for MG-23D

Workover of these wells by reaming the scales with the use of a drill rig has been found to be effective in recovering the output of each well. However, because of the relatively fast rate of calcite deposition in Mahanagdong, the use of chemical inhibitors is being considered. This may provide a more cost-effective method of calcite scale prevention.

References

Arnorsson, S. (1989) Deposition of Calcium Carbonate Minerals from Geothermal Waters – Theoretical Considerations. Geothermics, 18, 33-39.

Benoit, W.R. (1989) Carbonate Scaling Characteristics in Dixie Valley, Nevada Geothermal Wellbores. Geothermics, 18, 41-48.

Ellis, A.J. (1963) The solubility of Calcite in Sodium Chloride Solutions at High Temperatures. American Journal of Science, 261, 259-267.

Fournier, R.O. and Potter, R.W. (1982) A revised and expanded silica (quartz) geothermometer. Geothermal Resources Bulletin, Nov: 3-12

Martinez, M. (1997) Mineral Alteration in acid and neutral-pH hydrothermal reservoir: The case of Mahanagdong Field, Leyte. Proceedings of the 19th Annual PNOC-EDC Geothermal Conference. pp. 299-307.

Salonga, N., Parilla, E., Siega, F. and Alcober E. (1996) Geochemical constraints during development drilling and future production in Mahanagdong-B, Leyte. PNOC-EDC internal report.