THE EFFECT OF INFLOWING INJECTION FLUIDS ON CALCITE SCALING IN THE MAHANAGDONG GEOTHERMAL PRODUCTION FIELD, LEYTE, PHILIPPINES

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ABSTRACT

Some production wells in the Mahanagdong geothermal field have positive Calcite Saturation Indices (CSI) at lower flash point temperatures as calculated using the WATCH speciation program. From the start of production in ***1997,*** *the calcite-scaling wells have shown progressive decline in output as a result of mineral deposition and constriction in the wells' internal diameter.*

In ***1999,*** *injected brine was observed to be returning to three production wells and has caused marked decline in the CSIs of the wells. The invading fluids increased the reservoir chloride concentration and lowered the discharged CO_2 and the temperature of the well nearest to the injection sink. The carbonates of the deep fluids also decreased with the decline of dissolved CO_2. Since these species participate in the formation of calcite scales ($Ca^{2+} + 2HCO_3^- = CaCO_{3,s} + CO_2\uparrow + H_2O$), their decline lowered the CSI.*

The distribution of injection load was optimized in order to continuously provide mass recharge without necessarily cooling to the production wells. The modified injection strategy also aims to lower the potential for calcite deposition and effectively decrease the non-condensible gas content of the steam delivered to the power plants.

1.0 INTRODUCTION

The Mahanagdong geothermal field is one of the geothermal systems formed along the Philippine fault that bisected the island of beyte. It is found southeast of Tongonan geothermal field (Fig. 1) and covers an area of about 10 km². The two fields are part of the reserve called the Greater Tongonan Geothermal Field (GTGF). Although both are geographically close to each other, the reservoirs of the two operating fields are separated by the cold (<200 °C) impermeable Mamban block (Alvis-Isidro et al., 1993).

Because of the presence of the topographic low traversed by Mamban River (Fig. 1), development of Mahanagdong is divided into sectors Mahanagdong-A (MG-A) and Mahanagdong-B (MG-B). Thirteen production wells from pads MG1, MG2D, MG3D and MGSD supply steam to the 120 MW main power plant of MG-A while seven production wells in MGDL pad supply the steam requirement of the 60 MWe main power plant in MG-B. The separated brine from MG-A are injected into the wells of pad MGRDI while that of MG-B into the wells of pad MGB3.

Commercial operations of the power plants and of the Fluid Collection and Disposal System

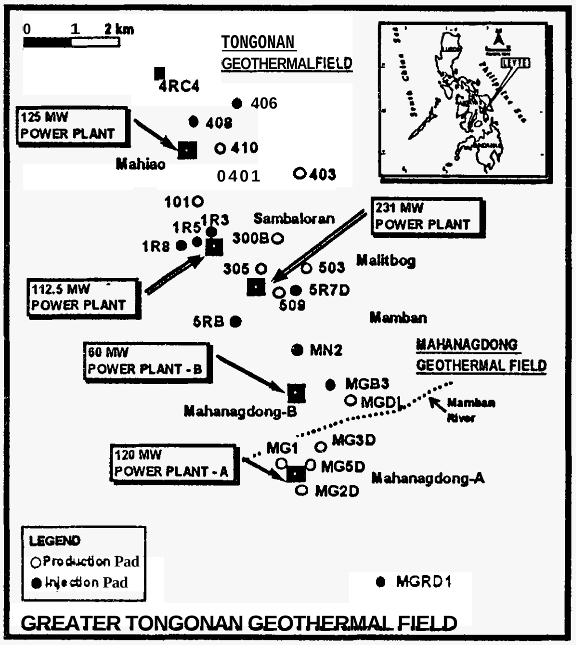

Figure 1 Location map of Mahanagdong geothermal field as part of the Greater Tongonan Geothermal Field (GTGF).

(FCDS) of Mahanagdong started in July 1997. From then, some production wells, mostly in the western region, developed calcite scales inside the wells that caused the progressive decline of their total massflow. Continued extraction of geothermal fluids also brought along changes in the reservoir. In 1999, pressure drawdown induced the inflow of the brine injected at MGRD1 pad back into the production sector.

This paper studies the impact of the encroaching brine to the deposition of calcite in the production wells. For this purpose, the three wells in the Southwestern sector which had injection return (MG-7D, MG-16D and MG-22D, Fig. 2) and had calcite-scaling potential even before the entry of injected fluids, were used in this study.

2.0 CALCITE SCALING IN THE PRODUCTION WELLS OF MAHANAGDONG

Several production wells in Mahanagdong showed high potential for calcite deposition even before exploitation of the field. Martinez (1997) evaluated the mineral saturation indices of all the production wells and found that the pre-flashed reservoir fluids of neutral-pH wells, which have temperatures of 260°C to 280°C, have calcite within the saturation levels. Based on simulations using the WATCH speciation program, these fluids when flashed at lower temperatures, which is the condition when the deep fluids are ascending to the wellhead, have the tendency to become supersaturated with calcite (Fig. 3) and hence, have high potential to deposit them. The maximum Calcite Saturation Index (CSI = log Q/K) is usually reached at temperatures between 230°C to 260°C.

The Mahanagdong reservoir is liquid-dominated with discharge enthalpies below 1600 J/g for the majority of the production wells. Because of this, the first and the consequent levels of boiling or flashing happen in the vertical channel of the wells where blockages are mostly tagged by downhole surveys. Wells which have confirmed mineral blockages include MG-1, MG-2D, MG-7D, MG-19, MG-22D and MG-23D. In MG-7D, the obstructions were tagged at 780 mMD (meters measured depth) by a 6" Go-Devil (GD) tool in July 1999 and at 1019 mMD by a 5" GD tool. Vertical clearing discharge was attempted to rid the bore of blockages. However, post discharge surveys tagged similar

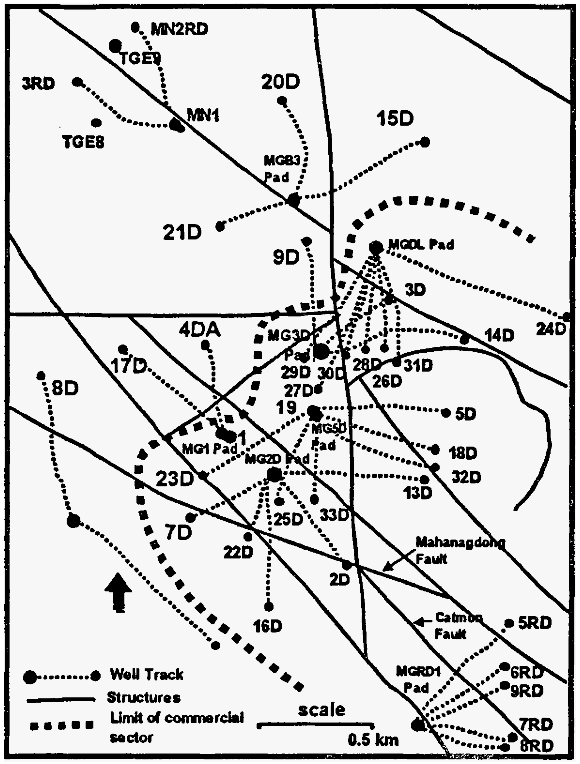

Figure 2. Well track map of Mahanagdong production and injection wells with some of the major structures.

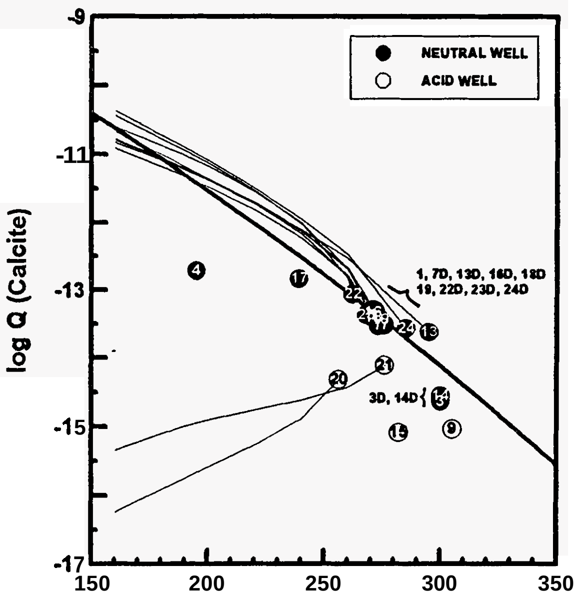

Figure 3. Calcite saturation of Mahanagdong wells at preflashed and at lower flash point temperatures (data from Martinez, 1997).

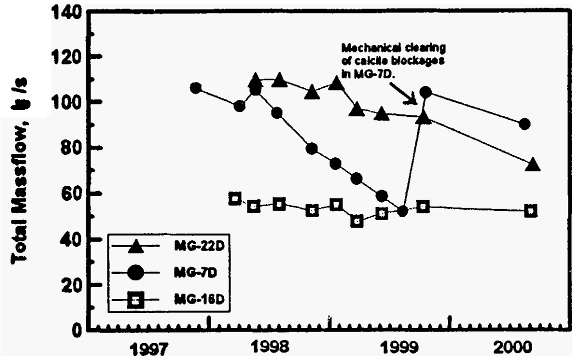

Figure 4. Historical trends of the measured total massflow of MG-7D, MG-16D and MG-22D.

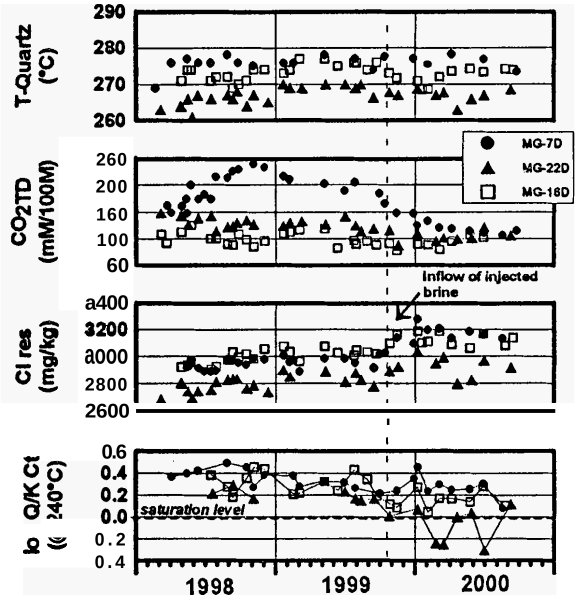

Figure 5. Historical trends of Calcite Saturation Indices (log Q/K) and of the geochemistry of MG-7D, MG-16D and MG-22D.

obstructions at almost the same depths. Ejecta samples collected during the vertical discharge consist of 50% carbonate scales. The scales are composed of 1.5 mm thick bond of interlocking fine to medium-grained (0.25-1.0 mm) calcite and rare aragonite crystals. Most of the calcite crystals are thinly rimmed by smectite scales and very fine-grained opaques. The continued deposition of calcite scales in the wellbore of MG-7D caused the progressive decline of its measured total massflow from 105 kg/s in May 1998 to 66 kg/s in March 1999 (Fig. 4) or a decline of 39 kg/s in 10 months. Mechanical drill-out of scales was conducted in August 1999 which resulted to an increase of its massflow to 104 kg/s.

Before exploitation and all through the production period, the CSI of MG-16D at 240°C has always been above saturation. In fact, the index of saturation is almost equal to that of MG-7D and MG-22D (Fig. 5). The growth of calcite scales in this well, if there is any, is considered very slow compared to MG-7D and MG-22D as evidenced by the slight decline or almost stable measured total massflow (Fig. 4).

In MG-22D, the blockage inside its casing was tagged at around 1005-1010 mMD during July 1999 (6" GD tool) and July 2000 (6" GD tool) downhole surveys. Solid scale samples ejected during the vertical discharge of the well in August 2000 consists of 97% calcite. The growth of calcite scales inside its wellbore is responsible for the continuous decline of its measured total massflow from 108 kg/s in January 1999 to 72 kg/s in September 2000 or a decline of 36 kg/s in 20 months.

3.0 INCURSION OF INJECTED FLUIDS

Injection fluids were observed to have invaded the southwestern area of the field starting in the last quarter of 1999. The encroaching high chloride, low gas fluids were noted in MG-7D, MG-16D and MG-22D. Injection returns in MG-7D has been displayed by the steep increase in reservoir chloride (Cl res) from 3000 mg/kg in the first half of 1999 to 3200 mg/kg of year 2000. This was paralleled by the decline in CO_2 in its total discharge (CO_{2TD}) from 200 to 130 mM/100M (Fig. 5).

The reservoir chloride of MG-16D also rose from 3000 mg/kg to 3200 mg/kg. CO_{2TD} declined from 110-120 to 80-100 mM/100M during the same period. Among the three, this was the only well that showed thermal deterioration from 273-277°C to 269-273°C based on quartz geothermometry (T-Quartz or T-Qtz) of Fournier and Potter (1982).

MG-22D likewise showed the same trends. Its chloride increased from 2800 to 3000 mg/kg while its CO_{2TD} decreased from 120-130 to 90-120 mM/100M. No significant thermal deterioration was observed in this well. Its T(Quartz) remained relatively stable at 267 to 270°C.

Based on chemical and structural evaluation, these new fluids have the chemical

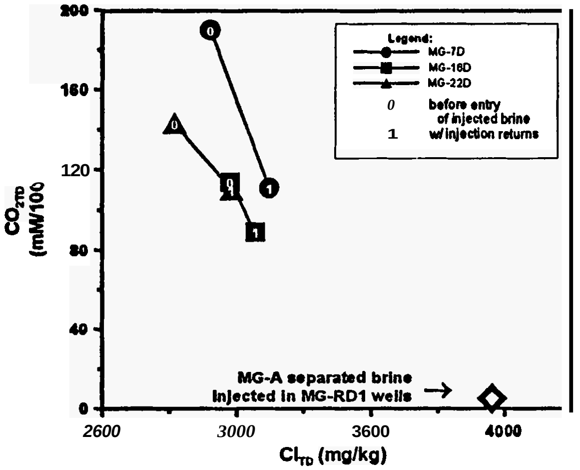

Figure 6. Crossplot of CO_2 and Cl in the total discharge of wells MG-7D, MG-16D and MG-22D before and during the incursion of injected brine.

signatures of the separated brine injected at MGRDI pad. Figure 6 is a crossplot of Cl and CO_2 in the total discharge of the three wells before and during the entry of injected fluids. The common shift of the data points indicated mixing with the separated brine of MG-A that are injected in MGRD1 wells. The separated brine is postulated to be coming from injection wells, MG-5RD, MG-6RD and MG-9RD through the highly permeable Catmon fault, which then courses to the three production wells through their common intercept, the Mahanagdong fault (Fig. 2).

Up to the latest geochemical update in September 2000, the highly saline, degassed injection fluids are still evident in the local reservoir of the three wells. The injection wells believed to have the hydrological connection with the production wells are still utilized since the returns provide mass recharge and they effectively reduce the over-all non-condensible gas content of the steam delivered to the power plant. Only MG-5RD was placed off the system in order to reduce the thermal impact of the cooler injection fluids to MG-16D.

4.0 EFFECTS OF INJECTED FLUIDS TO CALCITE DEPOSITION

From the start of entry of injected fluids in the last quarter of 1999, the saturation indices of MG-7D, MG-16D and MG-22D generally decreased (Fig. 5). In fact, there were instances when the CSI of MG-22D fell below the saturation level (i.e. 0) indicating that the calcite deposition activity has decreased for MG-7D and MG-16D and completely did not deposit during some occasions for MG-22D. The reason for this likely lies on the carbonate species that participate in the formation of calcite.

The important parameters that govern the deposition of calcite include P_{CO2} (fugacity or partial pressure of dissolved CO_2), pH, temperature and Ca^{+2}. Arnorsson (1989) discussed two mechanisms by which hydrothermal calcite deposits. One is through hydrolysis wherein the basic reaction is given by:

$$CaCO_{3,s} + 2H^+ = Ca^{+2} + CO_2 + H_2O \qquad \text{(Eq. 1)}$$

However, this reaction is favored in slow moving fluids which reacts with the rocks under sub-boiling conditions.

The second mechanism is through boiling. Calcite precipitation is represented by

$$Ca^{2+} + CO_3^{2-} = CaCO_3 \qquad \text{(Eq. 2)}$$

Under normal conditions, however, most dissolved carbonate ions are in the form of carbonic acid (H_2CO_3) or bicarbonate (HCO_3^-) as shown by the following reactions:

$$CO_{2(gas)} + H_2O = H_2CO_{3(aq)} \qquad \text{(Eq. 3)}$$

$$H_2CO_{3(aq)} = H^+_{(aq)} + HCO^-_{3(aq)} \qquad \text{(Eq. 4)}$$

$$HCO^-_{3(aq)} = H^+_{(aq)} + CO^{2-}_{3(aq)} \qquad \text{(Eq. 5)}$$

Combining equations 3 to 5

$$2HCO^-_{3(aq)} = CO^{2-}_{3(aq)} + H_2O + CO_{2(gas)}\square \qquad \text{(Eq. 6)}$$

show what happens during boiling. 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. Adding equations 2 and 6 gives

$$Ca^{2+} + 2HCO^-_{3(aq)} = CaCO_{3(solid)} + H_2O + CO_{2(gas)}\square \qquad \text{(Eq. 7)}$$

which shows that calcite precipitates by exsolving CO_2 gas. Flashing leads to a strong reduction in CO_2 partial pressure due to transfer of CO_2 into the steam phase that forms.

According to Arnorsson (1978), the 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 calcite saturated geothermal water supersaturated through boiling.

In the case of Mahanagdong, it is this second mechanism of calcite precipitation that greatly impacts the output of production wells. This is supported by the fact that calcite blockages are tagged, through downhole surveys, inside the casing where the ascending geothermal fluids flash.

On the lowering of the index of supersaturation, it must be noted that the brine injected in MG-RD1 wells, in comparison with that of the production wells, are almost completely depleted of CO_2. This is because it has already passed through the separator vessels where the separated brine is practically stripped off of its gas content. So, during the continuous inflow and mixing of injected brine, the resulting CO_2 content of the local reservoir of the' three production wells become significantly lower (Table 1). From this, it follows that the carbonates or bicarbonates which forms from the dissociation of dissolved CO_2 as described in the equations above, are also lowered. Therefore, the amount of calcite that may be formed during flashing or boiling becomes limited by the lower concentration of the carbonate species, hence, the lower CSI observed. It is also implied in this case that even with the influx of calcium-rich injected brine, the degree of supersaturation of calcite was not influenced by the enrichment of calcium ions.

5.0 CONCLUSION

Some production wells in Mahanagdong registered decline in their measured total massflow because of calcite deposition inside the wells. The mechanism by which this calcite precipitates is mainly through flashing of the ascending fluids that are initially saturated with the said mineral.

Pressure drawdown induced the inflow of injected brine into the production wells **MG-7D, MG-16D** and **MG-22D,** which are proximate to the southern injection sink of MG-A. The inflow of the injected brine reduced the deposition of calcite which is reflected in the decline of Calcite Saturation Indices in the three wells. The significant decline of CO_2 that resulted from the inflow of this highly-degassed fluids played a major role in lowering the deposition of calcite in the production wells. Ultimately, it is the decline of carbonate concentration, which is a consequence of the decline of the concentration of dissolved CO_2, limited the amount of calcite that could be formed during flashing.

Table 1. Representative chemistry of the injected brine and of the three production wells before and during the inflow of the injected brine.

	MGRD1 Injected Brine (1/00)	MG-7D		MG-16D		MG-22D	
		0* (5/99)	1** (3/00)	0* (5/99)	1** (1/00)	0* (7/99)	1** (3/00)
pH (25°C)	8.2	6.7	6.9	6.7	6.8	6.3	6.4
Cl (ppm)	3870	2980	3200	3070	3190	2880	2990
Ca (ppm)	46	20	28	23	42	25	25
CO_2 (ppm)	5.2	5019	2875	2766	2193	2936	2366
HCO_3 (ppm)	5.5	37	26	29	21	26	18
CSI (240°C)	-	+0.33	+0.30	+0.33	+0.27	+0.17	-0.25
T-Qtz (°C)	155 (meas.)	278	276	277	271	269	269

NB: *0* before inflow of injected brine from MGRD1 pad.
1 during inflow of injected brine**
The Cl, Ca, CO2 and HC03 of the three production wells represent the concentrations at the reservoir condition calculated using WATCH program. For the injected brine, these represent the chemistry at the wellhead before injection.

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