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Calcite Deposition of Wells Affected by Re-injected Fluids in Palinpinon II, Southern Negros Geothermal Production Field, Philippines

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ABSTRACT

This work investigated the calcite-inhibiting property of re-injected (RI)-fluids. Calcite solubility and calcite saturation indices (CSI) data for wells NJ3D, NJ5D, NJ7D from Y2000 to Y2006 were established. With the use of tracer data and computed void-volume-ratios at each well's permeable zones, the calcite-inhibition property of RI-fluids was examined.

From this study, the calcite-inhibition property of RI-fluids needs to be re-assessed. It was likely that the available void-volume for deposition in reservoir-rock was the primary factor that dictates how obstructive calcite deposition would be in steam production. The deposition triggered by mixing of in-situ well fluid with RI fluid would be less obstructive in wells with bigger void-volumes than those with smaller void-volumes.

1. INTRODUCTION

It is usually claimed that mixing injected brine with production well fluids can inhibit calcite deposition. This was commonly based from mixing simulation models, wherein in-situ reservoir was mixed with injected brine. But on actual steam-field operation, seldom do simulations coincide with actual observations. Clear examples are a significant number of wells affected by re-injected (RI) brine deposited calcite (Barroca et al., 2006; Zaide-Delfin and Rosell, 2004). Although not fully understood, outlook tends to be predisposed to accept calcite-inhibiting property of RI-brine.

In Southern Negros Geothermal Production Field (SNGPF), similar claim seems to be accepted. In this study, this claim will be examined by evaluating the solubility and calcite saturation indices (CSI) of selected wells, together with results of the latest tracer data evaluation (Maturgo et al., 2005; Sanchez et al., 2006).

Tracer test using naphthalene disulfonates (NDS) was conducted in the Palinpinon-II sector of SNGPF from February, 2004 to March, 2005. It was conducted to optimize well utilization and injection strategy towards sustained steam availability.

Earlier works (Barroca et al., 2004, 2005) established the homogeneity of the initial chemistry of the Palinpinon II reservoir. With time, the initial reservoir chemistry changed as optimal production-injection scheme was adapted. Re-injected fluids are continuously detected and monitored in several production wells close to the Nasuji and Sogongon injection sinks. Of these RI-affected wells, NJ3D and NJ5D are the most prominent. Expectedly, after the tracer test, NJ3D and NJ5D had the highest tracer mass recovered: NJ3D had 39.2%, while NJ5D had 25.2% (Sanchez et al., 2006). These values are proportional of RI-mix in their respective aquifers. These data also complement the established geochemical trend of RI-affected well (Barroca et al., 2006).

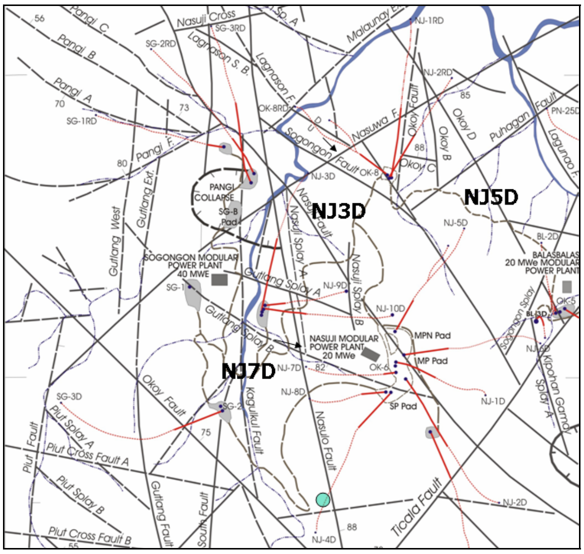

Figure 1: Structural map of Palinpinon II highlighting wells NJ3D, NJ5D, and NJ7D. Injection sink is located north of NJ3D and NJ5D wells. RI-fluids injected in SG2RD were traced to NJ3D (RI-mix = 39.2%), while fluids injected in NJ2RD were traced to NJ5D (RI-mix=25.2%). No tracer was detected in NJ7D (Sanchez et al., 2006).

For well unaffected by RI-fluids, NJ7D is notably the representative of the in-situ Palinpinon II reservoir fluid. True enough, no tracer was detected in this well during the test. Through the years, its geochemical trend also concurred with the established behavior of a well free from RI-fluids (Barroca et al., 2006).

In relation to history of calcite deposition of these three wells, NJ5D and NJ7D had undergone a series of work-over to remove the calcite blockages inside these boreholes. Interestingly, NJ3D remained free from any work-over activities (Zaide-Delfin and Rosell, 2004; PNOC-EDC, 2002).

Assuming that RI-fluids can inhibit calcite deposition, NJ5D should also be free from calcite blockage, like NJ3D. But this is not the case as evinced by the series of work-over to remove these deposits in NJ5D. Even if one argues that the RI-mix (25.2%) in NJ5D may not be enough to prevent calcite deposition, NJ3D should have manifested deposition in its early years of utilization, before the RI-mix reached its current level of 39.2%. Apparently, NJ3D's borehole remains free from calcite. Clearly, there are other factors that need to be considered before claiming the calcite-inhibition property of RI-fluids.

This study, using calcite solubility, CSI, and tracer data-computation, will identify other factors that may be controlling calcite deposition in RI-mixed aquifers.

2. METHODOLOGY

Most of the data sets that were used in this study cover data from Y2000 to Y2006. This period was selected to correspond to tracer test conducted last Y2004 to Y2005. In evaluating calcite solubility of each well, partial pressure of CO_2 (pCO_2 in atm) was computed given the CO_2TD and Henry's constant at given reservoir temperature (Tqtz). Calcite saturation indices (CSI) were computed at reservoir temperature given Tqtz using WATCHWORKS (Arnorsson et al., 1982). The dataset included in the study was limited to those with measured enthalpy similar to saturation enthalpy of Tqtz. This ensures saturated reservoir condition and consistency in Tqtz and pCO_2 calculations.

Given pCO_2 and Tqtz, calcite solubility graphs were generated using the data of Ellis (1959). Eventually, solubility (in mg-calcite/kg-water) was graphically obtained for each well data using these graphs.

After establishing the calcite-deposition property of each well, the void-volume of the immediate permeable zone along the given feed-zone was computed using TRINV program (Axelsson, 2002) and the method of Sanchez et al., (2006), given the tracer data. The ratios between the void-volume of the immediate permeable zone and the volume of the borehole at the given feed-zone were evaluated. These ratios or VVR (void-volume-ratio) between the immediate permeable zone and the borehole were computed to evaluate the relative volume capacity at each feed-zone near the borehole. Apparently, large VVR's have bigger capacity to contain deposition outside the borehole than smaller VVR's. Corollary to this, deposition outside the borehole will less likely obstruct well's total flow. For this study, only VVR's of NJ3D and NJ5D were computed. No ratios were computed for NJ7D because no tracer was detected in this well.

3. RESULTS AND DISCUSSION

The results of calcite solubility as a function of Tqtz and pCO_2 are shown in Figure 2. From Y2000 to Y2006, these wells attained an almost isothermal condition despite the high proportion of RI-mix in NJ3D and NJ5D. Their Tqtz range from 265 to 270^oC, with standard deviation of 5^oC (see table below). Considering that temperature was a major factor in calcite deposition, data shows that the well fluids attained isothermal state, and temperature had minimal effect, if any, on calcite deposition.

Well	Average Tqtz (^oC) from Y2000-06	Standard Deviation (^oC)
NJ3D	269	5
NJ5D	265	5
NJ7D	265	6

The major indicator of injected fluids was the declining value of pCO_2 as the RI-mix increases. Using NJ7D as the baseline well free from RI-fluids (average pCO2 = 4.670 atm), the pCO_2 decreases as the RI-mix increases: from NJ5D at 25.2% RI mix and average pCO2 of 2.400 atm, to NJ3D with 39.2% RI and average pCO2 0.480 atm. This resulted to decrease in calcite-solubility.

Investigating Figure 2 using CSI in Figure 3, notable trend was observed. The RI-free well NJ7D is calcite-supersaturated, while the well with the highest amount of RI-fluid, NJ3D, is close to calcite saturation. NJ7D has the highest CSI (+0.60) and solubility (ranging from 15.0-25.0 mg/kg) while NJ3D attained close to equilibrium (CSI ~ 0.00) and lowest solubility (8.0-13.0 mg/kg). Between these sets of data is NJ5D with CSI of +0.35 and mid-level solubility (14.0-17.0 mg/kg).

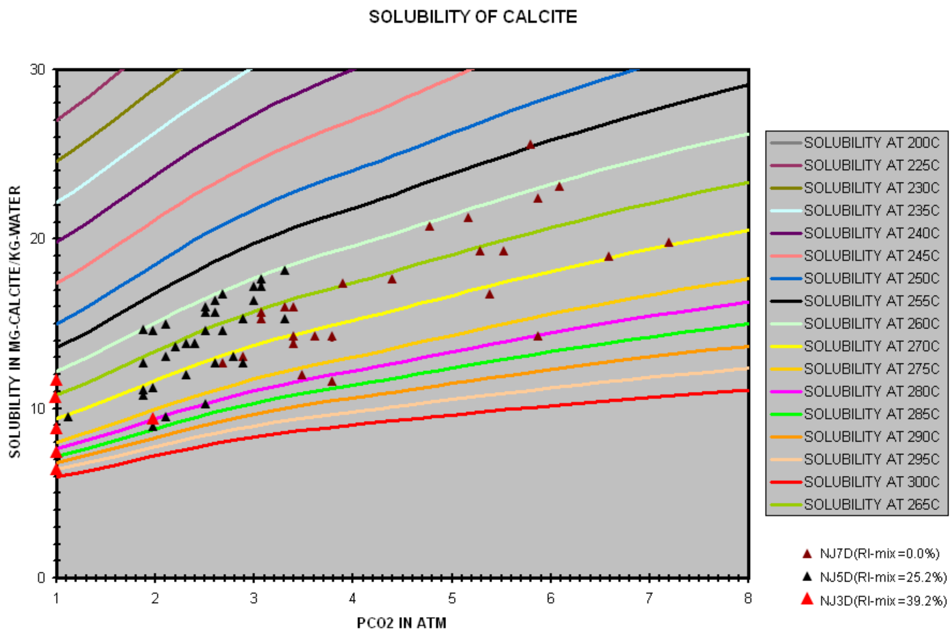

Figure 2: Calcite solubility of NJ3D, NJ5D, and NJ7D. Solubility is obtained by plotting pCO2 to its closest reservoir-temperature (as Tqtz). NJ3D has the highest RI-mix of 39.2%, followed by NJ5D at 25.2%), while NJ7D represent well free of RI-fluids.

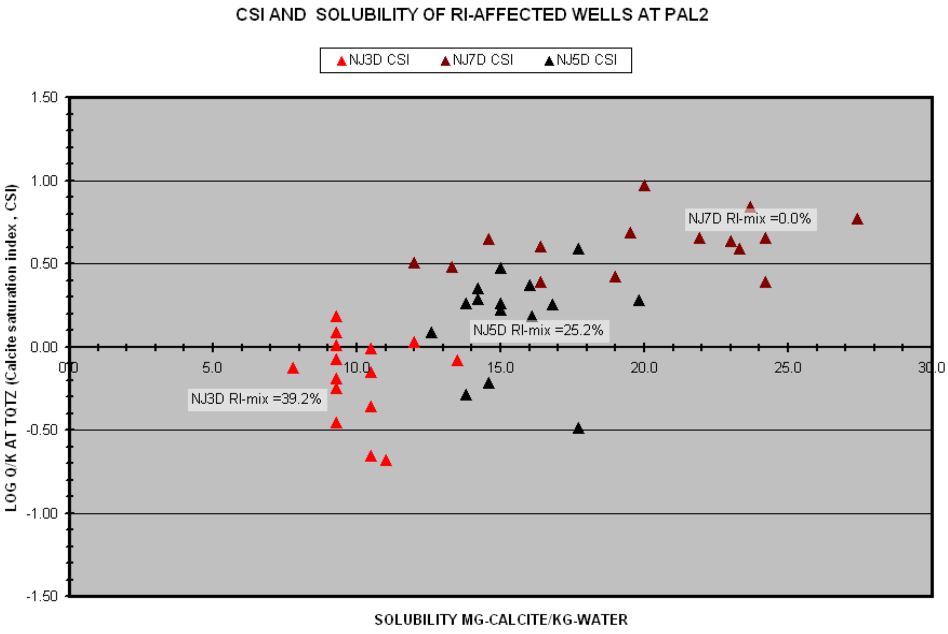

Figure 3: Calcite-saturation indices (CSI) NJ3D, NJ5D, and NJ7D plotted with calcite solubility. Note the decreasing solubility and CSI as RI-mix increases. This trend typically indicates active calcite deposition as the portion of RI-fluids in geothermal brine increases.

Figure 3 shows the drop from super-saturation to equilibrium as solubility decreases. It is a typical trend one expects of active calcite deposition. The trend indicates, at homogenous initial reservoir chemistry and isothermal condition, that increasing RI-mix enhances deposition. If this is true, the question is why no deposit was found in NJ3D considering it had the highest RI-mix, and why there was deposition in NJ7D, despite it being RI-free.

To answer this inconsistency, the results of VVR (Sanchez et al., 2006) are employed. The computed VVR for NJ3D and NJ5D and other tracer parameters are shown in Table 1a and 1b:

VVR of NJ3D at its permeable zones ranges from 388 to 2549, with its major zone at 613. For NJ5D, it ranges from 67 to 414, with its major zone at 67. As discussed earlier, VVR is the ratio of the void-volume at the immediate permeable zone and the borehole. Larger VVR, indicates bigger volume to contain deposition outside the borehole.

Comparing their respective VVR's at the major feed-zone, NJ3D has a bigger VVR (613), which may explain the absence of borehole-deposition in spite of its high RI-mix. It is likely that RI-fluids enhanced deposition but due to the bigger volume of the permeable zone outside the borehole, calcite deposited in the formation and not inside the well. Eventually, as its fluids' deposited its calcite in the formation, its fluids attained equilibrium as it entered the well.

For NJ5D, with its lower VVR's, one expects that the volume of immediate permeable zones are not enough to contain deposition away from the borehole. Hence, borehole deposition is expected within the permeable zones. These are substantiated by the presence of calcite blockages inside the well, within the permeable zones (PNOC-EDC, 2002).

For NJ7D, being RI-free, its deposition is likely caused by boiling and not by mixing with RI-fluids. Depths of its borehole deposition do not coincide with any permeable zones, but rather coincide with flashpoint depth of the well. Blockage tagged at lower depths, not coincident with any feed-zone or flashpoint depth, may still be caused by flashing triggered by drawdown, as flashpoint depth tends to go down with time during exploitation.

Based on these data and observations, the calcite-inhibiting property of RI-fluids need to be re-assessed. Based from this study, they could even enhance calcite deposition. For wells affected by RI-fluids, obstructive borehole calcite deposition is dictated by available volume near the entry at each feed zone (or void-volume-ratio VVR). The larger VVRs give bigger room to contain deposition in the formation than smaller VVRs as evinced by NJ3D and NJ5D.

This calcite enhancing property of RI-fluids is to be anticipated. At homogenous initial reservoir chemistry and isothermal condition, calcite deposition by RI-fluids could be initiated by:

$$2HCO_{3^-} + Ca^{2+} = CaCO_3(s) + CO_2(g) + H_2O$$

RI-fluid chemistry has two critical properties that enhances deposition: it has high Ca^{2+} and low dissolved $CO_2(g)$ or low pCO_2. These properties, once mixed with in-situ geothermal fluids, are expected to push the reaction forward, boosting calcite formation. Although a similar reaction is involved in deposition by flashing, with basically loss of CO_2 during boiling, RI-fluids carry a similar potential to deposit because of its lower CO_2 combined with higher Ca^{2+}.

Table 1a: Computed physical dimension of each permeable zone in NJ3D using TRINV program and the method devised from Sanchez et al., (2006). Porosity of minor and major zones are evaluated to be 1.5% and 7.6%, respectively, based from the Amistoso et al., (1993). NJ3D's VVR or the ratio of void-volume of the immediate vicinity ($V_{vicinity}$) and the 9 5/8" borehole (V_{well}) ranges 388 to 2549.

PRODUCTION WELL	NJ3D	NJ3D	NJ3D
Name of Permeable Zone	Zone A	Zone E	Zone C
H, HEIGHT IN M	91	264	113
b, WIDTH IN M	21.93	39.3	100.6
POROSITY %	7.6	1.5	1.5
Mr (percent mass recovery)	39.2	39.2	39.2
T, TQTZ IN C	268	268	268
TOTAL VOID VOLUME OF PERMEABLE ZONE (V_F IN M^3)	2,611	4,801	13,466
VOID VOLUME DRILLED OUT BY 9 5/8" (0.244 M) CASING FROM PERMEABLE ZONE IN M^3 (V_L)	0.323	0.185	0.079
VOID VOLUME AROUND THE VICINITY OF THE 9 5/8" (0.244 M; $V_{VICINITY} = V_F - V_{WELL}$) IN M^3	2,607	4,789	13,461
VOLUME OF WELL'S PRODUCTION CSNG (V_{WELL} IN M^3)	4	12	5
$V_{VICINITY}/V_{WELL}$ (or VVR)	613	388	2549

Table 1b: Computed physical dimension of each permeable zone in NJ5D using TRINV program and the method devised from Sanchez et al., (2006). Porosity of minor and major zones are evaluated to be 1.5% and 7.6%, respectively, based from the Amistoso et al., (1993). NJ5D's VVR or the ratio of void-volume of the immediate vicinity ($V_{vicinity}$) and the 9 5/8" borehole (V_{well}) ranges 67 to 414.

PRODUCTION WELL	NJ5D	NJ5D	NJ5D
Name of Permeable Zone	Zone X	Zone Y	Zone Z
H, HEIGHT IN M	87	104	178
b, WIDTH IN M	40.57	7.28	25.67
POROSITY %	1.5	7.6	1.5
Mr (percent mass recovery)	25.2	25.2	25.2
T, TQTZ IN C	263	263	263
TOTAL VOID VOLUME OF PERMEABLE ZONE (V_F IN M^3)	1,686	329	1,381
VOID VOLUME DRILLED OUT BY 9 5/8" (0.244 M) CASING FROM PERMEABLE ZONE IN M^3 (V_L)	0.061	0.389	0.125
VOID VOLUME AROUND THE VICINITY OF THE 9 5/8" (0.244 M; $V_{VICINITY} = V_F - V_{WELL}$) IN M^3	1,682	324	1,373
VOLUME OF WELL'S PRODUCTION CSNG (V_{WELL} IN M^3)	4	5	8
$V_{VICINITY}/V_{WELL}$ (or VVR)	414	67	165

4. SUMMARY AND CONCLUSIONS

Using data from Y2000 to Y2006 of wells NJ3D, NJ5D, and NJ7D, evaluation of calcite solubility using partial pressure of CO_2, reservoir temperature (Tqtz) and calcite saturation indices (CSI), the calcite-deposition properties of each well were established. Together with the tracer data and use of void-volume-ratios (VVR) of the immediate permeable zone at each feed-zone, the calcite-inhibition property of RI-fluids was investigated.

From this investigation, it is evident that RI-fluids calcite-inhibiting property needs to be re-examined. Based on this study, at initial homogenous reservoir and isothermal state, RI fluids seem to promote calcite deposition in the borehole if there is not enough space to deposit in the formation.

This calcite enhancing property of RI-fluids is feasible; RI-fluids, having both high Ca^{2+} and low dissolved CO_2(g), are expected to push the calcite deposition reaction forward, enhancing calcite formation.

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