A Test of Calcium Carbonate Scale Inhibition in Chingshui Geothermal Field, Taiwan

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ABSTRACT

A 3MW geothermal power plant at Chingshui geothermal field was built in 1981 and was decommissioned in 1993 due to continued declines in well production. Deposit and plugging wellbore caused by calcium carbonate scale was a major reason for reduced production. The purpose of this study was to investigate the inhibition efficiency of representative wells IC-9, IC-13 and IC-19 in Chingshui geothermal field. A downhole geothermal fluid sampler was conducted at a representative depth of 800 m in IC-19 to gather data on the formation fluid and for the analysis of scaling potential. Two kinds of inhibitors, Sodium Polyacrylate and Polyacrylate Acid, were tested in-situ. The difference of calcium concentration before and after dosage was used as an index for inhibition efficiency calculations. The inhibition efficiency of Sodium Polyacrylate was better than Polyacrylate Acid, but not significantly different. The exponential relationship between inhibitor concentration and efficiency was obtained; it can be a reference for maintenance cost calculation of Chingshui geothermal power plant.

1. INTRODUCTION

Chingshui geothermal field is located in the northeast portion of Taiwan, in the metamorphic terrain. The reservoir is within the Lushan Formation of Miocene age. The Lushan Formation lithologically includes the Jentse, Chingshuihu, and Kulu Members. The Chingshui geothermal field is located on a monoclinal structure, which is cut internally by numerous thrust faults that are lightly curved (Chiang et al., 1979). As shown in Figure 1(a), three of the most important faults, including the G fault, the Xiaonanaoa fault and Chingshuihsia fault, are distributed in Chingshui geothermal field (Tong et al., 2008). Well-developed fractures in these faults are observed. The best developed fractures in the slates are found near the most convex part of the Xiaonanaoa fault along the Chingshui River (Chen et al., 2011). Evidence shows that the geothermal reservoir is fracture dominated. However, due to the poor porosity and permeability of the slates, faults, joints, and other extensive fractures actually provide the conduits for the geothermal fluid flow. Geothermal production at Chingshui is largely from a fracture zone in the steeply dipping Jentse Member, which is comprised mainly of metasandstones intercalated by slates. As shown in Table 1, the water chemistry of Chingshui fluid is high in pH value (6.3-9.4) and rich in bicarbonate ions (HCO₃⁻) and carbonate ions (CO₃²⁻), therefore causing high potential of calcium carbonate scaling. Many researchers believe that the most important reason for the production capacity drop was carbonate scaling in the downhole (Liu et al., 1986; Lin, et al., 2011; Lu et al., 2012).

Figure 1(b) shows 8 old wells and 2 new wells (IC-20 and IC-21) in the Chingshui area. 8 old wells were used during 1981-1993 for the 3 MW geothermal power plant operations. Unfortunately, by 1993, the pilot power plant was decommissioned due to continued decline in production to uneconomic levels. Deposit and plugging of the wellbore caused by calcium carbonate scale was a major reason for reduced production and evidence of the scaling in the old wells was found (ITRI, 2008). Although there are many methods which can be utilized to control wellbore scaling problem, the calcite inhibition system (CIS) is one of the most common and useful methods to reduce wellbore scaling rates (Crane et al., 1981; Kooray et al., 2002; Moya et al., 2002; Ramos-Candalaria et al., 2000; Siega et al., 2005; Trazona et al., 2001). The conceptual operation of CIS is dosing inhibitor from a surface pump through tubes to appropriate depths (i.e. below flash depth) downhole to reduce scaling rate. The main purpose of this study was to construct CIS and tested two kinds of inhibitors: Sodium Polyacrylate (SP) and Polyacrylate Acid (PA) in wellbore of IC-9, IC-13, and IC-19 in Chingshui area. The study also used a downhole sampler to gather data on the formation fluid for analysis of scaling potential. The appropriate dosing depth and inhibition efficiency of inhibitor are discussed subsequently.
2. PRINCIPLE OF CALCITE INHIBITION

Geothermal fluids often contain appreciable quantities carbon dioxide in reservoir pressure and temperature conditions. Production of fluid from the reservoir results in a pressure reduction and therefore reduced solubility of calcite in the produced fluid. Once the pressure of the flowing fluid has reached the flash pressure downhole, further reductions in pressure will cause calcite to deposit (Segnit et al., 1962; Ellis and Golding, 1963; Ellis, 1963; Satman et al., 1999). Calcite forms primarily because of the disequilibrium that occurs when thermal waters boil or lose gas in response to a pressure drop. Most dissolved CO₂ is lost from solution at the point of first boiling (the flash point) and this causes a pronounced shift in the following equilibrium to the right:

\[
\text{CaCO}_3 (\text{solid}) + \text{CO}_2 (\text{aq}) + \text{H}_2\text{O} = \text{Ca}^{2+} + 2\text{HCO}_3^-
\]

Calcite deposition is most common in relatively alkaline-ph reservoirs, particularly those with high HCO₃ and CO₃ or relatively low temperatures (e.g. < 220°C). Deposition rates are highest when the original dissolved gas content is high because the carbonate concentrations are generally also high and the equilibrium change when CO₂ is lost is large. According to Henry’s Law, at
temperatures in the range 150-200°C the partial pressure of dissolved CO\textsubscript{2} passes through a maximum. Figure 2 shows steady-state temperature profile comparing with 3% CO\textsubscript{2} results before production when the fluid is liquid. Table 2 shows chemical analysis of scaling of IC-9 (ITRI, 2008). We used X-ray diffraction method to analyze mineral content of scaling from the well. The result of the semi-quantitative analysis of minerals showed the carbonate mineral compositions were comprised of Calcite (CaCO\textsubscript{3}), Aragonite (CaCO\textsubscript{3}), Ankerite (CaFe\textsubscript{2}(CO\textsubscript{3})\textsubscript{2}), and Strontianite (SrCO\textsubscript{3}). Silicate mineral composition is comprised of Chlorite, Illite and Feldspar. The evidence of calcite carbonate scaling in Chingshui geothermal well was therefore obtained.

Though CIS is a mature technology, the inhibitor test should be completed according to local conditions. Dosage concentration and inhibition efficiency are the main factors for economic considerations. Table 3 summarizes different types of inhibitor and dosage concentrations used in several geothermal fields. Crane et al. (1981) reported that dosages of 2.5ppm of Dequest 2060 can effectively inhibit the growth of calcium carbonate. Other reports also show that dosages of low concentrations of inhibitor can reduce the rate of calcium carbonate scaling (Moya et al., 2005; Ramos-Candelaria et al., 2000; Siega et al., 2005; Bignall et al., 2005). Most of the above mentioned inhibitors are Sodium Polyacrylate or Polyacrylate Acid, thus this study tested these two inhibitors in the Chingshui geothermal wellbore.

### Table 2: Scaling chemical analysis of IC-9 in Chingshui geothermal area (with weight percentage).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Calcite (CaCO\textsubscript{3})</th>
<th>Aragonite (CaCO\textsubscript{3})</th>
<th>Ankerite (CaFe\textsubscript{2}(CO\textsubscript{3})\textsubscript{2})</th>
<th>Strontianite (SrCO\textsubscript{3})</th>
<th>Quartz (SiO\textsubscript{2})</th>
<th>Illite</th>
<th>Chlorite</th>
<th>Feldspar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>18.44</td>
<td>28.56</td>
<td>20.74</td>
<td>32.24</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>50-100</td>
<td>21.25</td>
<td>35.58</td>
<td>9.16</td>
<td>33.88</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>100-150</td>
<td>13.79</td>
<td>42.67</td>
<td>8.55</td>
<td>33.07</td>
<td>1.93</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>150-200</td>
<td>18.79</td>
<td>40.28</td>
<td>7.01</td>
<td>33.06</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>200-250</td>
<td>13.63</td>
<td>45.15</td>
<td>6.21</td>
<td>34.10</td>
<td>0.93</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>250-300</td>
<td>8.20</td>
<td>50.18</td>
<td>8.13</td>
<td>31.98</td>
<td>1.51</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>300-350</td>
<td>35.10</td>
<td>23.04</td>
<td>8.46</td>
<td>32.34</td>
<td>1.06</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>350-400</td>
<td>8.05</td>
<td>49.27</td>
<td>6.88</td>
<td>32.35</td>
<td>3.45</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>400-450</td>
<td>19.57</td>
<td>52.85</td>
<td>12.59</td>
<td>13.82</td>
<td>1.16</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>450-500</td>
<td>56.50</td>
<td>16.61</td>
<td>12.87</td>
<td>13.53</td>
<td>0.49</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>928</td>
<td>76.10</td>
<td>8.51</td>
<td>10.77</td>
<td>3.85</td>
<td>0.77</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
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<tr>
<td>957</td>
<td>77.92</td>
<td>7.29</td>
<td>10.68</td>
<td>3.88</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>1300</td>
<td>48.14</td>
<td>16.84</td>
<td>11.48</td>
<td>14.87</td>
<td>2.30</td>
<td>1.77</td>
<td>3.62</td>
<td>0.98</td>
<td>100</td>
</tr>
<tr>
<td>1311</td>
<td>18.48</td>
<td>31.98</td>
<td>9.53</td>
<td>14.52</td>
<td>5.40</td>
<td>4.66</td>
<td>10.48</td>
<td>4.95</td>
<td>100</td>
</tr>
<tr>
<td>1436</td>
<td>19.13</td>
<td>39.15</td>
<td>7.42</td>
<td>32.87</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>1605</td>
<td>35.13</td>
<td>27.76</td>
<td>9.42</td>
<td>27.17</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>1980</td>
<td>36.21</td>
<td>23.15</td>
<td>16.80</td>
<td>10.49</td>
<td>3.27</td>
<td>3.43</td>
<td>6.63</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>2010-2020</td>
<td>49.74</td>
<td>18.94</td>
<td>14.54</td>
<td>9.78</td>
<td>1.72</td>
<td>1.13</td>
<td>3.23</td>
<td>0.91</td>
<td>100</td>
</tr>
<tr>
<td>2040-2060</td>
<td>21.19</td>
<td>12.74</td>
<td>4.42</td>
<td>38.56</td>
<td>4.62</td>
<td>18.46</td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 3: Inhibition in calcium carbonate scale type.

<table>
<thead>
<tr>
<th>Site</th>
<th>Type</th>
<th>Temperature</th>
<th>Scaling type</th>
<th>Inhibitor</th>
<th>Dosing concentration (ppm)</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA-East Mesa Field</td>
<td>Volcanic</td>
<td>200-220°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Dequest 2060</td>
<td>2.5</td>
<td>1978</td>
</tr>
<tr>
<td>Turkey-Kizildere</td>
<td>Volcanic</td>
<td>200°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Dequest 2066</td>
<td>n.a.</td>
<td>1984</td>
</tr>
<tr>
<td>Philippines- Mahanagdong</td>
<td>Volcanic</td>
<td>240-260°C</td>
<td>CaCO\textsubscript{3}</td>
<td>DG9349</td>
<td>2</td>
<td>2001</td>
</tr>
<tr>
<td>New Zealand-Kawerau</td>
<td>Volcanic</td>
<td>269°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Hydrophilat 5040</td>
<td>few ppm</td>
<td>2005</td>
</tr>
<tr>
<td>Costa Rica- Miravalles</td>
<td>Volcanic</td>
<td>240°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Nalco 1340 HP Plus</td>
<td>0.5-2.5</td>
<td>1994</td>
</tr>
<tr>
<td>Philippines- Mindanao</td>
<td>Volcanic</td>
<td>240°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Nalco 9354</td>
<td>3-5</td>
<td>1999</td>
</tr>
<tr>
<td>Philippine/Japan</td>
<td>Volcanic</td>
<td>250°C/200°C</td>
<td>CaCO\textsubscript{3}</td>
<td>Belclene 110</td>
<td>4-5</td>
<td>--</td>
</tr>
</tbody>
</table>
3. CALCITE INHIBITION SYSTEM

The Chingshui CIS design and construction is shown in Figure 3. CIS consists of four main units, comprising of inhibitor, downhole equipment (sinker bar and nozzle) and surface equipment (lubricator, workbench, winch, dosing pump, tank etc.). Related system parameters and size are shown in Table 4.
Table 4: Parameter of calcite inhibition system.

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
<th>Item</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antiscalant</td>
<td>Sodium Polyacrylate Polyacrylate Acid</td>
<td>Workbench</td>
<td>Height 8.4m</td>
</tr>
<tr>
<td>Dosing tube</td>
<td>Material: SS316L</td>
<td>Winch</td>
<td>Loading capacity 1000kg↑</td>
</tr>
<tr>
<td>Dosing tube</td>
<td>Length:1500m</td>
<td>Winch</td>
<td>Down:35m/min↑ · Up:15m/min↑</td>
</tr>
<tr>
<td>Dosing tube</td>
<td>Diameter:φ0.25&quot; thickness0.049&quot;</td>
<td>Winch</td>
<td>Power 15HP</td>
</tr>
<tr>
<td>Sinker bar</td>
<td>Material: SS316L</td>
<td>Winch</td>
<td>Wire tension, depth, speed, record</td>
</tr>
<tr>
<td>Sinker bar</td>
<td>Length:4×1.25m</td>
<td>Dosing pump</td>
<td>Max. B.P.: 10Mpa · rate:10L/h</td>
</tr>
<tr>
<td>Sinker bar</td>
<td>Ø5cm weight:74kg</td>
<td>Dosing pump</td>
<td>Including bypass:10Mpa</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Material: SS316L</td>
<td>Tank</td>
<td>Volume:2m³</td>
</tr>
<tr>
<td>Nozzle</td>
<td>4×Ø2mm length:0.3m</td>
<td>Tank</td>
<td>Material: High-density polyethylene</td>
</tr>
<tr>
<td>Recovery spool</td>
<td>Length:6m, Ø6&quot;</td>
<td>Colorimeter</td>
<td>HACH CEL/890</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. DOWNHOLE PARAMETERS IN CHINGSHUI GEOTHERMAL AREA

Table 5 summarizes reservoir parameter results from production, injection test and downhole sampling of IC-9, IC-13 and IC-19. Based on the parameters as shown in Table 5, the study calculated flash depth in downhole using WellSim software. Dosing depths were set below the flash point according to Table 6.

Table 5 Reservoir parameters in Chingshui geothermal area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed zone</td>
<td>1,200 m</td>
</tr>
<tr>
<td>Pressure</td>
<td>100 kg/cm²</td>
</tr>
<tr>
<td>Temperature</td>
<td>215°C</td>
</tr>
<tr>
<td>Enthalpy</td>
<td>220 kcal/kg</td>
</tr>
<tr>
<td>Permeability-thickness(kh)</td>
<td>0.3 darcy-m</td>
</tr>
<tr>
<td>Skin damage effect (s)</td>
<td>5.0</td>
</tr>
<tr>
<td>Calcium concentration (C₁)</td>
<td>8.77 ppm</td>
</tr>
</tbody>
</table>

Table 6 Simulated flash depth of Chingshui geothermal reservoir.

<table>
<thead>
<tr>
<th>Pressure at wellhead (kg/cm²)</th>
<th>Steam (ton/hr)</th>
<th>Hot water (ton/hr)</th>
<th>Total discharge (ton/hr)</th>
<th>Flash depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.8</td>
<td>18.2</td>
<td>20</td>
<td>880</td>
</tr>
<tr>
<td>7</td>
<td>2.4</td>
<td>21.6</td>
<td>24</td>
<td>1000</td>
</tr>
<tr>
<td>6</td>
<td>3.2</td>
<td>26.8</td>
<td>30</td>
<td>1150</td>
</tr>
</tbody>
</table>

5. SCALING INHIBITION TEST

Two kinds of inhibitor Sodium Polyacrylate (SP) and Polyacrylate Acid (PA) were tested in IC-9, IC-13 and IC-19 downhole in Chingshui geothermal area. Optimal dosing depth was based on Table 6 and through trial tests in each well. The optimal dosing depth is shown in Figure 4.

Calcite deposition changes calcium concentrations within the original fluid after flash. Calcite deposition reduces the calcium concentration of the original fluid, and vice versa. We therefore assume that inhibitor can reduce carbonation reaction and keep calcium concentration within the fluid even though the system reached flash pressure. Furthermore, the study uses the difference of calcium concentration before and after dosage at weirbox (Figure 5) to calculate an index for inhibition efficiency:

\[ E_{\text{inhibition}}(\%) = \frac{C - C_b}{C_c - C_b} \times 100\% \]  

where C is Ca²⁺ concentration at weir after dosage, C_b is Ca²⁺ concentration at weir before dosage and C_c is Ca²⁺ concentration in the reservoir. We used a downhole sampler to collect and analyze the C_c which was 8.77 ppm before flash in the IC-19 downhole.
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The value was close to WEST JEC (2009) calculation of calcite saturation in the Chingshui reservoir water as shown in Figure 6. The highest Ca²⁺ concentration of around 9.8 ppm and was recorded for the brine in the IC-19 production test in 2006.

Figure 4: Inhibitor dosing depths in wellbore of IC-9, IC-13 and IC-19.

Figure 5: Sampling at weir for calcite inhibition test.

Figure 6: Calculation of calcite saturation in the Chingshui reservoir (WEST JEC, 2009).
6. RESULTS AND DISCUSSION

According to optimal dosing depth, the study has tried many dosing concentration to find out the best dosing condition. The results for inhibition efficiency in IC-9, IC-13 and IC-19 are shown in Figure 7. The relationship of inhibitor concentration and calcium concentration shows an exponential trend. Higher inhibitor concentrations can obtain higher calcium concentrations. Calculation of inhibition efficiency based on Equation (1) shows that a SP inhibitor concentration of 12ppm can obtain an efficiency of 23.3% in IC-9, a PA inhibitor concentration of 11 ppm can obtain an efficiency of 8.5% in IC-13 and a PA inhibitor concentration of 10ppm can obtain an efficiency of 20.1% in IC-19. The study has also used SP inhibitor concentrations at 84 ppm in IC-19. The result showed that both PA and SP in same trend, and higher inhibitor concentrations resulted in a higher inhibition efficiency of 78.8%. Overall the SP used in IC-9 was superior to the PA used in IC-13 and IC-19 when the inhibitor concentration is less than 30 ppm.

![Figure 7: Calcium concentration varying with concentration of inhibitor in geothermal fluid in IC-9, IC-13 an IC-19.](image)

7. CONCLUSION

This paper describes the construction of a calcite inhibition system based on features of the Chingshui geothermal well. According to inhibition experience with other geothermal sites, the study tested Sodium Polyacrylate and Polyacrylate Acid in Chingshui geothermal wells IC-9, IC-13 and IC-19 to find out the best dosing conditions.

Optimal dosing depth was based on flash depth calculations and through trial tests in each well. Afterwards, the study tried various inhibitor concentrations to find out the best dosing conditions. The relationship of inhibitor concentration and calcium concentration showed an exponential trend. A higher inhibitor concentration can obtain higher inhibition efficiency, e.g. 78.8% with 84 ppm SP inhibitor in IC-19. Overall, the SP used in IC-9 had superior performance than PA which was used in IC-13 and IC-19. However, both SP and PA should dose higher inhibitor concentrations and further studies of these and other inhibitors still need to be done.

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