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

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ABSTRACT

A 3MWe 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 monocline 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 Xiaonanao fault and Chingshuihsi 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 Xiaonanao 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 (HCO_3) and carbonate ions (CO_3), 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; Koorey et al., 2002; Moya et al., 2002; Ramos-Candelaria 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 inbitors: 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.

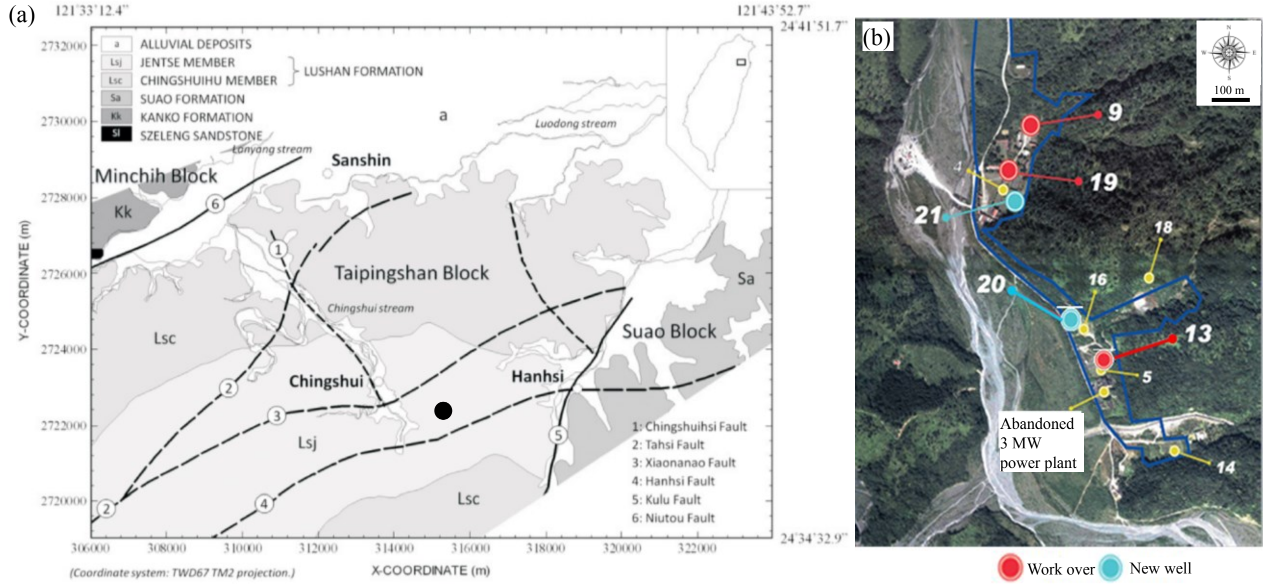

Figure 1: Generalised geological and location of geothermal well in the Chingshui area (Tong et al., 2008).

Table 1: Water chemistry in Chingshui geothermal area.

Well Name	Date	pH	Na	K	Li	Ca	Mg	Cl	SO_4	HCO_3	CO_3	T-HCO_3	SiO_2	B	Tqz-adia.	Tchal.	T Na/K(C)	T Na/Li
			mg/kg												°C			
IC-1	1975/12/2	8.9	826	22.0	-	1.7	1.1	16.5	25.0	2017	144	2163	182	17.9	-	152	232	-
IC-1	1976/1/11	8.9	826	22.5	6.5	2.3	0.8	14.1	51.5	1943	158	2104	179	23.1	-	150	234	234
IC-2	1976/8/15	8.0	866	33.0	-	-	-	21.5	15.0	2279	-	2279	223	33.6	-	168	257	-
IC-2	1976/10/17	8.3	818	35.0	-	0.8	<0.1	18.7	15.0	2374	-	2374	243	33.2	-	175	266	-
IC-2	1976/6/15	8.6	891	35.0	7.0	tr	tr	18.7	23.9	2121	133	2256	246	34.1	-	176	259	234
IC-2	-	6.3	845	40.0	-	1.2	0.1	17.7	31.2	2310	-	2310	225	-	-	168	274	-
IC-2	-	8.3	861	35.0	6.8	0.6	0.1	19.0	18.0	2387	-	2387	246	32.0	-	176	262	234
IC-4	1976/6/27	8.7	1320	40.0	-	0.8	0.9	37.4	27.0	3199	151	3353	404	32.2	211	-	241	-
IC-4	1976/10/17	8.8	1149	36.0	-	1.0	0.8	16.0	24.0	2768	186	2957	370	30.9	205	-	243	-
IC-4	1976/12/7	8.5	1095	36.0	-	0.6	0.2	18.3	32.0	2619	93	2714	342	34.0	200	-	247	-
IC-4	1978/11/5	9.3	1050	32.0	-	0.6	0.2	23.0	35.0	2045	416	2468	343	31.0	200	-	241	-
IC-4	-	9.4	1023	32.5	-	0.5	0.2	20.4	26.3	1760	469	2237	343	31.6	200	-	244	-
IC-4	-	8.7	1117	35.0	-	0.8	0.2	17.3	44.2	2862	-	2862	343	-	200	-	243	-
IC-4	-	8.7	1125	35.0	7.0	0.9	0.3	20.0	43.0	2633	127	2762	343	34.0	200	-	243	209
IC-5	1978/5/15	8.8	913	30.0	-	0.8	0.1	23.0	34.0	2219	176	2398	418	33.0	213	-	247	-
IC-5	-	9.1	923	32.5	8.0	0.7	0.1	23.1	26.8	2010	28.3	2039	364	36.7	204	-	251	245
IC-5	-	8.9	993	40.0	-	0.8	0.1	22.3	36.4	2644	-	2644	413	-	212	-	261	-
IC-9	1977/4/15	8.5	1168	28.0	-	1.3	0.5	21.0	32.0	2928	106	3036	321	34.0	196	-	225	-
IC-9	-	8.5	1235	29.0	-	1.3	0.5	21.2	32.3	3233	-	3233	321	-	196	-	224	-
IC-12	1978/2/20	8.9	1128	50.0	-	0.9	0.1	20.0	38.2	2453	229	2686	428	44.8	215	-	268	-
IC-13	1978/4/14	8.8	1013	42.5	-	0.7	0.1	23.3	25.8	2418	156	2577	418	41.5	213	-	264	-
IC-14	1978/12/26	9.3	1020	34.0	-	0.8	0.3	25.0	21.0	1631	448	2086	420	37.0	214	-	248	-
IC-14	-	9.4	938	77.0	7.7	0.7	0.2	24.7	14.0	1595	476	2079	429	23.0	215	-	320	239
IC-16	-	8.8	1000	80.0	8.3	0.4	0.2	28.9	16.0	2285	149	2436	480	32.8	223	-	318	240
IC-19 (before workover)	2006/8/7	9.0	962	35.8	8.6	9.8	0.4	28.6	77.9	4080	-	4080	4.7	14.8	-	-	255	248
IC-19 (after workover)	2007/3/20	8.9	1160	32.5	3.1	1.3	0.3	15.0	22.0	1890	-	1890	324	30.1	197	-	236	136

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 CO_2 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:

$$CaCO_3\ (solid) + CO_2\ (aq) + H_2O = Ca^{2+} + 2HCO_3^-$$

Calcite deposition is most common in relatively alkaline-pH reservoirs, particularly those with high HCO_3 and CO_3 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 CO_2 is lost is large. According to Henry's Law, at temperatures in the range 150-200°C the partial pressure of dissolved CO_2 passes through a maximum. Figure 2 shows steady-state temperature profile comparing with 3% CO_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 ($CaCO_3$), Aragonite ($CaCO_3$), Ankerite ($CaFeCO_3$), and Strontianite ($SrCO_3$). Silicate mineral composition is comprised of Chlorite, Illite and Feldspar. The evidence of calcite carbonate scaling in Chingshui geothermal wells 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).

Depth (m)	Calcite ($CaCO_3$)	Aragonite ($CaCO_3$)	Ankerite ($CaFe(CO_3)_2$)	Strontianite ($SrCO_3$)	Quart (SiO_2)	Illite	Chlorite	Feldspar	Total
0-50	18.44	28.56	20.74	32.24	0.02				100
50-100	21.25	35.58	9.16	33.88	0.14				100
100-150	13.79	42.67	8.55	33.07	1.93				100
150-200	18.79	40.28	7.01	33.06	0.86				100
200-250	13.63	45.15	6.21	34.10	0.93				100
250-300	8.20	50.18	8.13	31.98	1.51				100
300-350	35.10	23.04	8.46	32.34	1.06				100
350-400	8.05	49.27	6.88	32.35	3.45				100
400-450	19.57	52.85	12.59	13.82	1.16				100
450-500	56.50	16.61	12.87	13.53	0.49				100
928	76.10	8.51	10.77	3.85	0.77				100
957	77.92	7.29	10.68	3.88	0.22				100
1300	48.14	16.84	11.48	14.87	2.30	1.77	3.62	0.98	100
1311	18.48	31.98	9.53	14.52	5.40	4.66	10.48	4.95	100
1436	19.13	39.15	7.42	32.87	1.43				100
1605	35.13	27.76	9.42	27.17	0.52				100
1960	38.68	21.72	13.03	14.76	2.15	2.32	6.42	0.93	100
1980	36.21	23.15	16.80	10.49	3.27	3.43	6.63		100
2010-2020	49.74	18.94	14.54	9.78	1.72	1.13	3.23	0.91	100
2040-2060	21.19		12.74	4.42	38.56	4.62	18.46		100

Table 3: Inhibition in calcium carbonate scale type.

Site	Type	Temperature	Scaling type	Inhibitor	Dosing concentration (ppm)	Time
USA-East Mesa Field	Volcanic	200-220℃	$CaCO_3$	Dequest 2060	2.5	1978
Turkey-Kizildere	Volcanic	200℃	$CaCO_3$	Dequest 2066	n.a.	1984
Philippines- Mahanagdong	Volcanic	240-260℃	$CaCO_3$	DG9349	2	2001
New Zealand-Kawerau	Volcanic	269℃	$CaCO_3$	Hydropalat 5040	few ppm	2005
Costa Rica- Miravalles	Volcanic	240℃	$CaCO_3$	Nalco 1340 HP Plus	0.5-2.5	1994
Philippines- Mindanao	Volcanic	240℃	$CaCO_3$	Nalco 9354	3-5	1999
Philippine/Japan	Volcanic	250℃/200℃	$CaCO_3$	Belclene 110	4-5	--

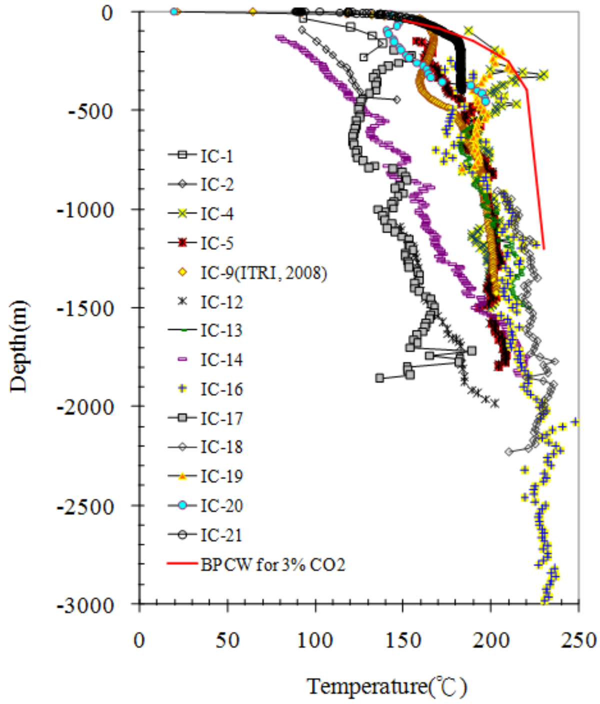

Figure 2: Steady temperature in Chingshui geothermal well.

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.

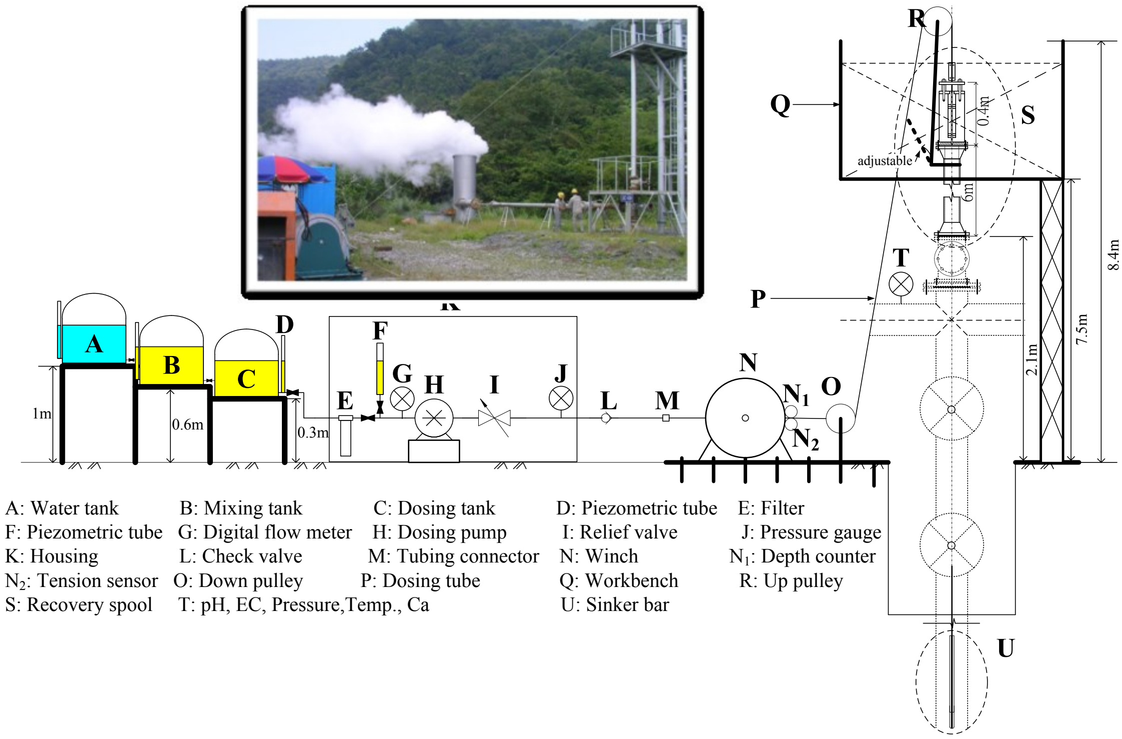

Figure 3: Calcite inhibition system in Chingshui geothermal area.

Table 4: Parameter of calcite inhibition system.

Item	Parameter	Item	Parameter
Antiscalant	Sodium Polyacrylate Polyacrylate Acid	Workbench	Height 8.4m
			Loading capacity 1000kg↑
		Winch	Down:35m/min↑、Up:15m/min↑
Dosing tube	Material: SS316L		Power 15HP
	Length:1500m Diameter:ϕ0.25” thickness0.049”		Wire tension, depth, speed, record
Sinker bar	Material: SS316L	Dosing pump	Max. B.P.: 10Mpa、rate:10L/h
	Length:4×1.25m ϕ5cm weight:74kg		Including bypass:10Mpa
Nozzle	Material: SS316L	Tank	Volumn:2m^3 Material: High-density polyethylene
	4×ϕ2mm length:0.3m		
Recovery spool	Length:6m, ϕ6”	Colorimeter	HACH CEL/890

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.

Parameter	Value
Feed zone	1,200 m
Pressure	100 kg/cm^2
Temperature	215^{o}C
Enthalpy	220 kcal/kg
Permeability-thickness(kh)	0.3 darcy-m
Skin damage effect (s)	5.0
Calcium concentration (C_c)	8.77ppm

Table 6 Simulated flash depth of Chingshui geothermal reservoir.

Pressure at wellhead (kg/cm^2)	Steam (ton/hr)	Hot water (ton/hr)	Total discharge (ton/hr)	Flash depth (m)
8	1.8	18.2	20	880
7	2.4	21.6	24	1000
6	3.2	26.8	30	1150

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:

$$E_{inhibition}(\%) = \frac{C - C_b}{C_c - C_b} \times 100\% \qquad (1)$$

where C is Ca^{2+} concentration at weir after dosage, C_b is Ca^{2+} concentration at weir before dosage and C_c is Ca^{2+} 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.

The value was close to WEST JEC (2009) calculation of calcite saturation in the Chingshui reservoir water as shown in Figure 6. The highest Ca^{2+} concentration of around 9.8 ppm and was recorded for the brine in the IC-19 production test in 2006.

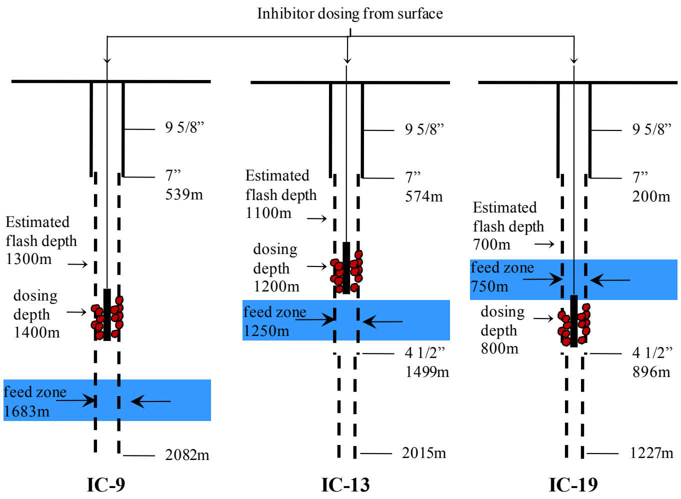

Figure 4: Inhibitor dosing depths in wellbore of IC-9, IC-13 and IC-19.

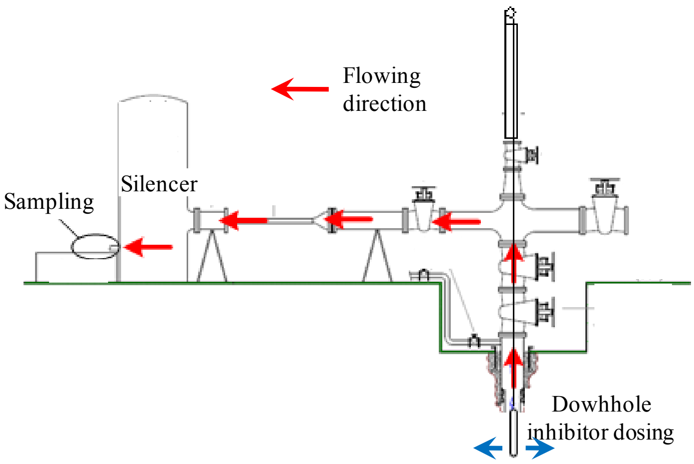

Figure 5: Sampling at weir for calcite inhibition test.

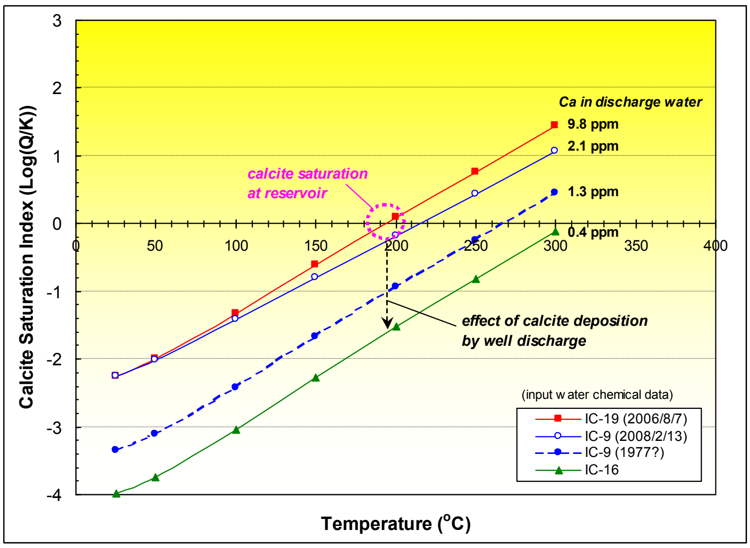

Figure 6: Calculation of calcite saturation in the Chingshui reservoir (WEST JEC, 2009).

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.

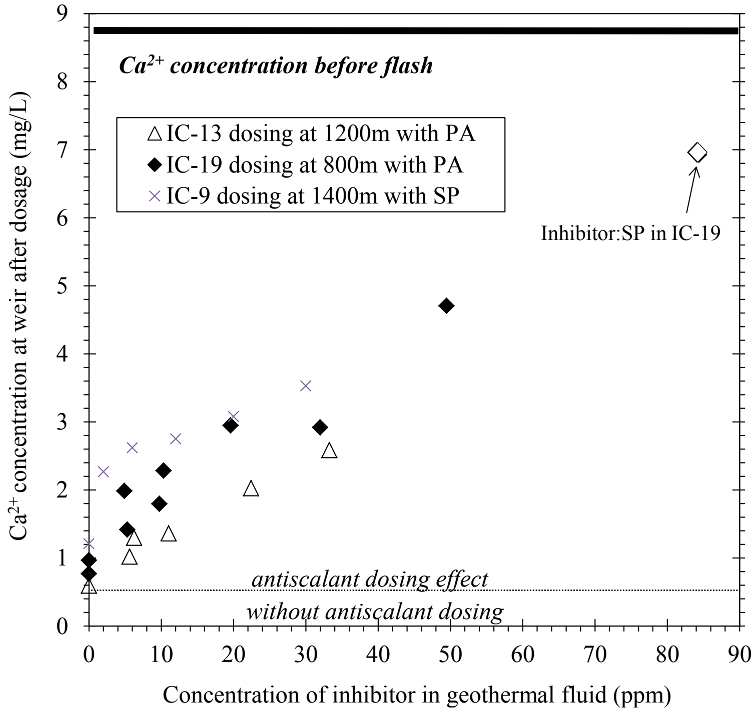

Figure 7: Calcium concentration varying with concentration of inhibitor in geothermal fluid in IC-9, IC-13 an IC-19.

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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