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SCALE INHIBITOR TESTING AT EAST MESA

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ABSTRACT

A pilot scale test facility was used to test four calcite scale inhibitor chemicals. The test facility was designed to reproduce process conditions of the 43 MWg GEM 1 power plant, which utilizes moderate temperature geothermal fluid from pumped wells and dual-flash steam separation at the power plant. The two most effective inhibitors were selected by simple, 24 hour atmospheric flash tests; they were tested more extensively in a dual-flash test configuration which modeled actual plant flash conditions. Additionally, laboratory tests were conducted to determine the effective longevity of the inhibitor chemicals. Monsanto Dequest 2060, a phosphonate-based product, was most effective at preventing scale formation, and was also most effective at delaying calcite precipitation at reservoir temperatures for up to 20 hours. These results are consistent with previous work by other authors.

INTRODUCTION

The East Mesa Geothermal System, located in the Imperial Valley of southeastern California, is a liquid-dominated, moderate temperature (175°C), low salinity (<1wt% total dissolved solids) geothermal resource. Geothermal fluid production at East Mesa is accomplished by down-hole pumping, which allows higher mass flow rates than down-hole flashing and maintains fluid pressures above gas and liquid saturation pressures. The single-phase fluid is delivered to the 43 megawatt-gross (MWg) GEM 1 power plant which utilizes a dual-flash steam separation process. Field experience, field testing and chemical modeling at East Mesa indicated that flashing of the geothermal fluid would result in calcium carbonate supersaturation, and precipitation of 25-100 kg of calcite per 1,000,000 kg of produced fluid where system pressures dropped below 80 psia. Under full 43 MWg load at GEM 1, where the first flash occurs at ~47 psia, this amounts to calcite precipitation rates of 88-354 kg/hr. This is considerably higher than the scaling tendency of 6.5 ppm_w calculated for the northern part of the East Mesa field (Vetter et al., 1979). Because these precipitation rates would scale the flash train shut in a matter of days, scale mitigation was required.

The first developers to use dual-flash technology at East Mesa, GEO Operator Corporation, a wholly-owned subsidiary of Geothermal Resources International, Inc., recognized that scale mitigation must be part of an integrated geothermal fluid treatment program. The program needed to minimize impairment of surface operations due to scaling, while controlling the concentrations of suspended and precipitated solids in the discharged fluid at levels undamaging to injectivity.

Research conducted during early development of the East Mesa resource determined that the high calcite scaling potential would inhibit commercial production (Vetter et al., 1979; Michels, 1981). However, field testing showed that inhibitor chemicals could cost-effectively decrease or eliminate calcite scaling in surface facilities (Vetter and Campbell, 1979). Scale inhibitor chemicals have also been lab and/or field tested for geothermal applications in Italy (Corsi et al., 1985), Turkey (Parlaktuna and Okandon, 1989), Dixie Valley, Nevada (Benoit, 1989), Coso, California (Lovekin, 1989), Heber, California (Korf, 1989), and elsewhere. Where tested, phosphonate products were generally most effective.

The scaling potential of fluid supplied to the GEM 1 plant, however, is distinct from geothermal fluids used in previous tests at East Mesa. For example, GEM 1 fluid contains 4-15 times more calcium in solution (Table 1). In addition, GEM 1 process conditions are also different, combining pumped wells with dual-flash steam separation.

Table 1 - UnFlashed Fluid Compositions

	Well 44-7	GEM 1	Well 56-30*
TDS (ppm)	6795	5935	--
Na (ppm)	2440	2042	600
Cl (ppm)	3570	3100	540
SiO_2 (ppm)	225	220	140
Ca (ppm)	25.6	23	5
Total CO_2 (ppm)	1370	1520	1040
HCO_3 (ppm)	488	480	~300
pH (units)	6.59	6.07	7.9
Temperature (°C)	172	174	157

*previously tested East Mesa fluid (Vetter and Campbell, 1979)

A pilot scale test was conducted to select the most cost effective calcite scale inhibitor available. Effectiveness was defined as minimum scale formation at the surface and minimal potential damage to the injection reservoir. The pilot scale test facility was designed to simulate the GEM 1 dual-flash power plant and injection system. Testing consisted of an initial screening to select the two most effective scale inhibitor chemicals, extensive testing in the dual-flash configuration, and laboratory 'bomb' testing at reservoir temperatures. Special attention was paid to the effects of inhibitors on suspended solids load, inhibitor longevity, and to other forms of fluid treatment such as filtration. The inhibitors tested were Nalco Dynacool 1382 (polyacrylate), Monsanto Dequest 2060 (phosphonic acid), Drew Milsperse 802 (polymaleic acid), and Betz DG-1181.

Test Fluid

The geothermal fluid used in this study was supplied by Well 44-7, centrally located in the GEO East Mesa field. It was selected for use because of its availabiliity and chemical similarity to that expected for the proposed GEM 1 power plant (Table 1).

METHODS

Screening Test Method

The screening test used a segment of the dual-flash test skid, from the inlet to CV102 (Figure 1). Geothermal fluid was delivered to the inlet by a slipstream from Well 44-7. Inhibitor was mixed with distilled water in a 55 gallon plastic drum. An Eldex precision metering pump injected the mixed inhibitor at a rate of 6 ml/minute into a mixing spool. The fluid flow rate was controlled at ~0.07 *l*/s. Temperature, pressure, inhibitor feed rate, and fluid flow rate were monitored. The fluid was flashed at CV-102 into pre-weighed, 46 cm long, 3 cm O.D. steel tubes. After 24±0.5 hours each test was completed and the steel tubes were dried and re-

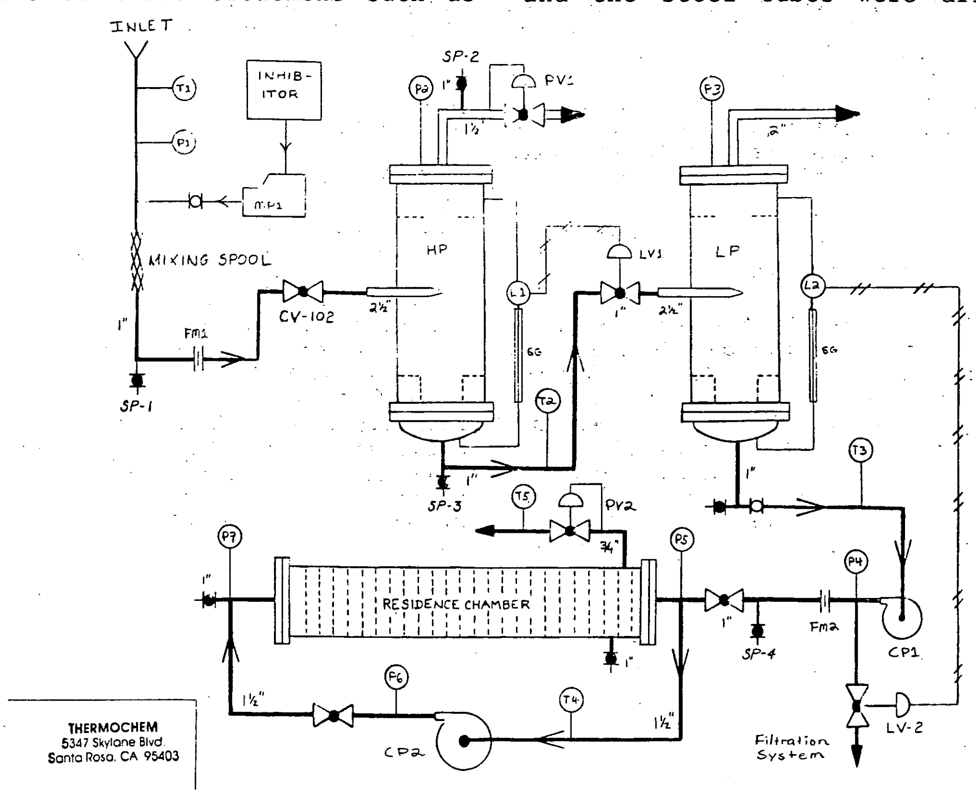


Figure 1 - Simplified schematic of dual-flash test apparatus

weighed to determine the mass of scale deposited. Scale tubes were not reused. Baseline scaling rates were established by three blank runs with no inhibitor, two at the beginning of the test and one near the end (Blank run #1 lasted only 14.7 hours).

Dual-Flash Test Method

Dual-Flash testing evaluated the performance of Nalco Dynacool 1382 and Monsanto Dequest 2060 at various concentrations. The test skid configuration was designed to replicate GEM 1 plant operating conditions (Figure 1, Table 2). Fluid and inhibitor were supplied and mixed as in the screening test. Initial flashing occurred at CV-102, the valve used to control the flow rate at ~0.62 *l*/s. The high pressure (HP) flash was maintained at ~48 psia by adjustment of PV1. The low pressure (LP) flash occurred at ~17 psia. Levels in both flash vessels were maintained with level control valves (LV-1, LV-2). A booster pump at the liquid outlet of the LP flash supplied flow to the residence chamber, where the minimum fluid residence time was maintained at ~13 minutes by adjustment of PV2; residence chamber time simulated time spent in the GEM 1 injection piping system. The residence chamber was outfitted with pre-weighed steel plates; they displayed negligible scale formation throughout the dual-flash tests. The remainder of the LP flash discharge was pumped through a filtration loop that was used to evaluate filtration systems. The spent liquid was discharged to an evaporating pond.

Each dual-flash test was scheduled for 14 days. Liquid and gas samples were typically collected at three day intervals. Samples were collected by flowing the sample fluid (at system pressures to prevent additional flashing) through teflon or stainless steel tubing to water-cooled condenser coils, and through a 0.2µm filter membrane. Samples were collected into 500 ml polyethylene bottles (for anion analysis), 250 ml polyethylene bottles acidified with 5 ml HNO_3 (cation analysis), or evacuated Giggenbach-type glass bottles treated with NaOH and $CdCl_2$ (gas analysis). Sample collection at low pressure ports was aided by pumping; a small peristaltic pump was used. Calcium analyses were performed by atomic absorption spectroscopy in the field lab and by ion-coupled plasma mass spectrometry at the University of Utah Research Institute in conjunction with comprehensive water analyses. Complete gas analyses were performed by Thermochem, Inc.

After each test run the flash train was opened and inspected, then cleaned before the next test. Massive scale deposited during Test 1 was soft and easily removed by scraping, etc. Scale deposited in the following tests was much harder, and removal was variously accomplished by scraping, sandblasting, waterblasting, and acid dissolution.

Inhibitor effectiveness was determined qualitatively by visual inspection of the flash train, and quantitatively by evaluation of calcium concentrations in the test fluid. After Test 1 the scale was removed and weighed; this was not possible in later tests due to small scale volumes and scale hardness. Scaling rates were calculated by determining the loss of calcium from the test fluid (after correcting for concentration due to flashing).

Bomb Test Method

Bomb tests were designed and conducted to determine the relative effectiveness of

Table 2 - Dual-Flash Test and GEM 1 Plant Conditions

	Test 1	Test 2	Test 3	Test 4	GEM 1
Inhibitor Tested	N-1382	N-1382	M-2060	M-2060	N-1382
Inhibitor Concentration (ppm)	1.0	4.4	3.2	2.0	8.0
Inlet Flow Rate ($lb/hr*10^3$)	4.005	3.960	4.459	4.450	7228
Inlet Temperature (°C)	172	172	172	172	174
Inlet Pressure (psia)	269.7	272.2	272.2	257.7	233.7
HP Flash Pressure (psia)	48.0	47.0	46.8	46.7	46.9
HP Flash Fraction (%)	7.08	7.25	7.26	7.30	7.60
LP Flash Pressure (psia)	16.84	16.88	17.15	17.15	16.23
LP Flash Fraction (%)	5.77	5.82	5.22	5.65	6.30
Injection Loop Time (minutes)	12.7	12.5	12.3	12.4	2-20
Total Inlet Fluid ($lb*10^6$)	0.888	1.452	0.703	1.302	----
Test Duration (days)	9.2	15.3	6.7	12.2	----
Ratios of Brine Flow Rate to Internal Surface Area of Vessel or Pipeline ($lbs/hr/ft^2$)					
HP Flash Vessel	486	480	540	539	964
LP Flash Vessel	451	445	501	500	809
Injection Loop	48.3	48.8	49.4	49.1	161

N-1382=Nalco Dynacool 1382; M-2060=Monsanto Dequest 2060 inhibitors in delaying calcite precipitation under injection conditions (in the reservoir; high temperature, extreme calcite supersaturation). Inhibitor-treated, dual-flashed test fluid was loaded into pressure bombs that were placed in a laboratory oven and removed at selected time intervals for analysis. Changes in calcium concentration were used as an indirect measure of calcite precipitation. Stainless steel bombs, 300 cc in volume, were equipped with valves at each end for sample transfer and a pressure relief valve to discharge excess fluid, without internal boiling, as it expanded with temperature. The bombs were pretreated with flashed fluid in a 132°C oven for 12 hours to passivate the internal surfaces and to deposit a film of calcite. The bombs were not acid-cleaned between tests in order to maintain a calcite nucleating surface.

Before filling, each bomb was flushed with N_2 to eliminate O_2, then flushed with fluid from the test skid for at least 10 minutes. For each test run, 5 to 8 bombs were filled with inhibited and flashed fluid, then placed in the laboratory oven at at temperature of 132°C. Bombs were also filled and immediately taken through the sample recovery steps without oven heating to determine initial calcium concentrations.

The bombs were removed from the oven at selected time intervals, weighed to determine fluid loss due to expansion (typically 5% or 15g), and immediately attached to the sample recovery system. A filter holder (0.2µm filter) and miniature condenser were attached to the bomb outlet. Pressurized N_2 was attached to the bomb inlet to force the fluid through the filter and condenser without flashing, while the condenser outlet valve slowly dispensed the fluid into a sample bottle. Total sample recovery time was less than 4 minutes, which minimized temperature decrease of the fluid before filtration. During each sample recovery operation two bombs were removed from the oven, sequentially, to provide duplicate results for each time interval.

RESULTS

Screening Test Results

Nalco Dynacool 1382 and Monsanto Dequest 2060 were tested first, each at three concentrations. Because this established a baseline for judging relative inhibitor effectiveness, it was only necessary to test the remaining two products (Betz DG-1181, Drew Milsperse 802) at two and one concentrations, respectively. Scaling rates were calculated as mass of precipitate deposited per mass of fluid flow (Table 3). The Monsanto product was clearly most effective at preventing scale formation (at two of the test concentrations no scale formed, and the mass of the scaling tube decreased, probably due to corrosion), followed by Nalco, Betz, and Drew, in that order. Thus, the Monsanto and Nalco products were selected for testing in the dual-flash configuration.

Oxbow Geothermal (Dixie Valley, Nevada) conducted a field test to determine relative effectiveness of various scale inhibitors for down-hole application. The products tested were supplied by Nalco, Betz (different product number), and Drew. Their results are consistent with those of the present test; the Nalco product was clearly more effective than both the Betz and Drew products (Benoit, 1989). Corsi et al. (1985) conducted laboratory testing of 7 different inhibitor chemicals; their laboratory test conditions were very similar to our screening test conditions. They found the most effective product to be Monsanto Dequest 2066 (the pH-neutralized version of Dequest 2060). Similarly, in down-hole testing, they found that the organic phosphonates, Monsanto Dequest 2066 and Eurosyn Chelone DPNA, were most effective at scale inhibition. With inhibitor concentrations of 400-500 ppm, they found no evidence of pseudo-scale (calcium phosphate) formation. Dequest 2060 successfully inhibited scale formation in earlier tests in the northern part of the East Mesa field, but formed psuedo-scale at inhibitor concentrations >7.5 ppm and temperatures of 132-160°C (Vetter and Campbell, 1979).

Dual-Flash Test Results

Nalco Dynacool 1382 and Monsanto Dequest 2060 were tested in the dual-flash configuration at two concentrations each. Calcium and sodium concentrations as measured at the test skid inlet (SP-1) and outlet (SP-4), and as calculated for the outlet by correcting the inlet concentration for steam loss, provide a quantitative analysis of inhibitor

Table 3 - Screening Test Results

Inhibitor	Inhibitor Conc. (ppm)	Scaling Rate[1]
Blank #1	0	10.5
Blank #2	0	14.2
Blank #3	0	17.7
Nalco D-1382	0.5	0.105
	1.0	0.021
	2.0	0.015
Monsanto D-2060	0.5	0.009
	1.0	-0.005
	2.0	-0.015
Betz DG-1181	0.5	0.472
	1.0	0.023
Drew M-802	0.5	2.966

[1]mg of scale deposited per kg of fluid flow

effectiveness (Table 4). The sodium values serve as a check of the accuracy of the calcium values (assuming no sodium loss in the system). The percent calcium lost in the flash system is calculated by comparing measured outlet concentration (O_m) to calculated outlet concentration (O_t) (Table 4, right-hand column).

Test 1 was terminated due to fluid flow restriction; examination of the flash vessels revealed that restriction was due to excessive calcite scale deposition. Scaling began where the pressure first dropped significantly (CV-102), with most scaling occurring in the high pressure separator. In Test 1 60-70% of the inlet calcium was lost to scale formation. Apparently, the scaling rate increased as the test progressed, as evidenced by an increase in wt.% calcium loss during the test (Table 4).

Total fluid flow during Test 1 was 403,000 kg, and the average scaling rate was 51.5 ppm $CaCO_3$, suggesting that ~20.7 kg of $CaCO_3$ was deposited in the test unit. The mass of scale removed from the flash train was 17.3 kg. Additionally, the filtration loop removed 0.86 kg of solids, mostly calcite, from the flashed fluid, for a total mass of 18.2 kg. The difference of 2.5 kg may be the result of using a mean instead of an integrated scaling rate, incomplete removal of scale from the flash train, and residual calcite particles filtered out during sample collection.

In Test 2 the inhibitor concentration was increased to 4 ppm, and the scaling rate declined to less than 20%. Again, it appeared that the scaling rate increased as the test progressed. Examination of the flash train revealed that the inhibitor was significantly more effective than at 1 ppm, with deposition of 0.5-1.0 kg (?) of scale, mostly in the HP flash vessel. The average scaling rate was 8.35 ppm $CaCO_3$ and the total fluid flow was 659,000 kg, suggesting that ~5.4 kg of $CaCO_3$ precipitated as pipe-wall deposits and suspended solids.

Test 3 evaluated Monsanto Dequest 2060 at a concentration of 3 ppm. This test was halted due to corrosion-induced failure of the inhibitor feed pump. Although the pump failure made qualitative assessment of the inhibitor effectiveness difficult, it was apparent that scaling was minimal during this test. Therefore, we decreased the inhibitor concentration in the following test.

Test 4 lasted 11.5 days and was discontinued when it appeared that the inhibitor feed pump was again on the verge of corrosion-induced failure. Scale deposition was minimal; there was slightly more than in the previous test at a concentration of 3 ppm for 6.5 days, but significantly less than the test of the Nalco product at a concentration of 4 ppm for 15.2 days. A very thin layer of scale formed at the inlet to the HP flash vessel and continued in a plume around the interior of the flash vessel. The scale in the high pressure separator was a maximum of 6-8mm thick near the fluid inlet. The scale appears as alternating white and green to black layers. Nine to twelve layers could be distinguished, suggesting that the white layers formed while the inhibitor feed pump rate was being calibrated. During each pump calibration the inhibitor feed was diverted for 4-10 minutes from the flash train. Field data logs indicate that this procedure was performed eight times during this test.

Table 4 - Dual-Flash Test Calcium Concentrations

Inhibitor Tested	Inlet Measured Ca	Inlet Measured Na	Outlet Measured (O_m) Ca	Outlet Measured (O_m) Na	Outlet Theoretical (O_t) Ca	Outlet Theoretical (O_t) Na	Wt.% Change at Outlet[2] Ca	Wt.% Change at Outlet[2] Na	Scaling[3] Rate (ppm)
N-1382/1ppm	26.8	2370	11.6	2770	30.6	2707	-62.1	-2.3	
	27.0	2390	9.6	3690	30.8	2730	-69.0	1.5	
	26.4	2360	8.7	2700	30.2	2695	-71.3	0.2	51.5
N-1382/4ppm	26.4	2360	29.7	2700	30.2	2702	- 1.7	-0.1	
	27.0	2430	27.2	2730	30.9	2782	-12.0	-1.9	
	26.1	2430	26.4	2750	29.9	2781	-11.7	0.1	
	26.3	2420	24.4	2770	30.1	2770	-18.9	-0.0	8.35
M-2060/3ppm	26.1	2420	29.1	2730	29.7	2770	- 2.0	-1.4	1.5
M-2060/2ppm	25.7	2430	29.3	2780	29.8	2778	- 1.7	0.1	
	25.6	2440	28.1	2740	29.3	2790	- 4.1	-1.8	
	25.6	2360	28.8	2730	29.3	2698	- 1.7	1.2	
	25.2	2340	28.9	2710	28.8	2675	0.3	1.3	
	25.4	2370	29.4	2750	29.0	2710	1.4	1.5	<1

All concentrations expressed in ppm
[1] O_t = Inlet concentration (ppm) corrected for steam loss
[2] O_m-O_t/O_t; wt% loss or gain of calcium and sodium
[3] Average $CaCO_3$ scaling rate for duration of test

Energy dispersive X-ray analysis indicates that the white layers are composed of up to 81% calcium with minor strontium (carbonate is not detected by X-ray dispersion). The green to black layers are composed of nearly equal fractions of silica and iron (35-40% each), with minor fractions of sodium, magnesium and calcium. These results indicate rapid deposition of calcium (and strontium) carbonate during pump calibration, and slow deposition of an iron silicate.

Although the results of filtration testing will not be discussed extensively here, they can be summarized with the following statements. Flow of inhibited fluid through cotton and synthetic string-wound cartridge filters caused rapid and extensive calcite precipitation on the filter media. Scanning electron micrographs of the filter material indicate that precipitation occurred on the filter itself, not in the fluid. Energy dispersive X-ray spectrometry suggests that the precipitate is almost exclusively calcium carbonate. Elongate crystal morphologies are characteristic of aragonite. Crystals formed during Test 1 (relatively poor inhibitor performance) were euhedral, whereas those formed during Test 2 are anhedral, occurring in botryoidal masses. The anhedral morphologies are indicative of distorted crystal growth, caused by reaction with the inhibitor chemical. With regard to injection, it is reasonable to assume that the sediments receiving injection fluid will act as a filter media, and may promote precipitation of calcium carbonate.

Dual Flash Test Simulation Validity

Dual-flash testing closely simulated GEM 1 plant process parameters such as inlet temperature, HP and LP flash pressures and, to a lesser extent, injection system residence time (Table 2; Table 5). The average HP steam fraction for dual-flash testing was about 5% lower than GEM 1 due to the slightly lower inlet temperature. Dual-flash testing LP steam fractions averaged about 10% lower than GEM 1 due to increased heat loss from piping connections between the test flash vessels, which were uninsulated. Lower test steam fractions resulted in proportionally higher steam phase gas concentrations, given similar inlet fluid gas content.

The ratio of fluid flow rate to surface area in each of the test flash vessels was 50-60% lower than the analagous vessels in GEM 1 (it was not possible to match these conditions more closely due to the nonlinear relationships of vessel and piping sizes to fluid dynamics), resulting in decreased scale deposit thickness in the test vessels relative to GEM 1 at similar mass deposition rates. The injection loop (residence chamber) fluid flow rate to surface area ratio for the test was set at about 30% of GEM 1

Table 5 - Dual-Flash Test[1] and GEM 1 Plant Chemistry

Analyte	Test Inlet	Test HP Steam	Test HP Liquid	Test LP Liquid	GEM 1 Inlet	GEM 1 HP Steam	GEM 1 HP Liquid	GEM 1 LP Liquid
Na	2440		2650	2740	2120		2329	2525
K	191		208	213	170		184	200
Ca	25.6		27.2	28.1	22.0		25.4	27.5
Fe	0.31		0.08	0.07	0.16		0.05	0.14
SiO_2	225		232	245	226		249	272
B	8.76		9.35	9.61	7.95		8.78	9.45
Li	7.5		8.12	8.39	6.44		6.99	7.57
Sr	5.45		5.81	5.97	4.91		5.41	5.84
As	0.57		0.58	0.56	<0.49		0.58	0.60
Ba	0.81		0.98	0.93	0.58		0.81	0.86
HCO_3	488		484	432	502		509	434
CO_3	<1		9	42	<1		19	40
Cl	3570		3800	3940	3165		3460	3680
SO_4	102		106	109	109		121	130
TDS	6795		7265	7510	6099		6670	7124
pH	6.59		8.60	9.10	6.04		8.70	9.16
Total Gas	1440	21200		348	1740	18400		
CO_2	1370	20400		335	1670	17700		
H_2S	0.55	9.51		0.57	1.17	9.42		
NH_3	17.4	98.4		12.0	14.9	87.5		
N_2	16.9	242		<0.03	17.9	230		
CH_4	29.9	467		<0.153	29.8	388		

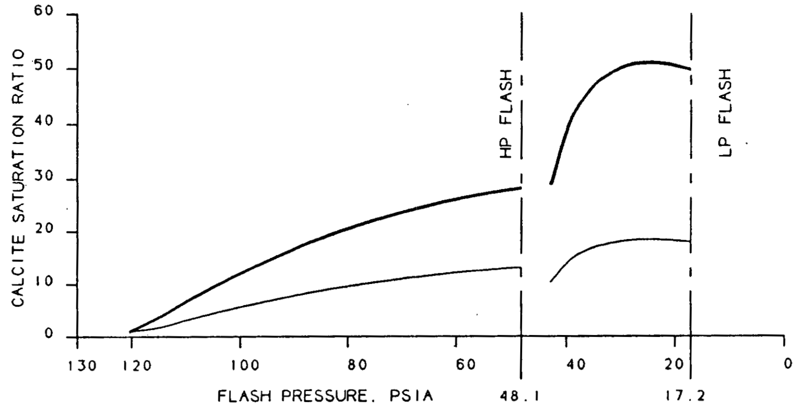
[1]Test Samples collected during Test 4
All concentrations expressed in ppm
CO_2 includes HCO_3
Refer to Figure 1 for sample port (SP) locations

injection system conditions in order to maximize the surface area for scale deposition on the test plates. Recirculation of fluid through the injection loop may have generated more turbulence than is currently experienced in the GEM 1 injection system (which now operates at lower fluid velocities than originally estimated and is experienceing scale deposition). Higher fluid turbulence in the test injection loop may have reduced the deposition of weakly adherent scales, even though more surface area was available for scaling.

In order to compare the fluid scaling potential of the dual-flash test to the GEM 1 plant, calcite saturations were calculated as a function of flash pressure using the chemical modeling program, WATCH (Svavarsson, 1981). For Test 1, calcite saturation ratios (Q/K; actual calcite solubility product [Q], equilibrium solubility product [K]) were calculated based on pre-flash chemistry assuming no deposition (scaling completely inhibited; Figure 2; upper curve) and also on post-flash chemistry with deposition at each flash stage (residual calcite saturation; Figure 2; lower curve).

The calcite saturation curve for GEM 1 (Figure 3), with essentially 100% scale inhibition (as indicated by calcium concentrations) is comparable to the saturation curve of complete inhibition for the dual-flash test (Figure 2). The maximum calcite supersaturation through the GEM 1 HP flash is higher than that calculated for Test 1, with a peak value of Q/K=37.4 versus Q/K=28.3. This is due to the higher CO_2 content of HP flash steam in GEM 1 compared to the dual-flash test (Table 5), which was the result of the lower HP flash fraction in the test.

The GEM 1 inlet fluid is slightly supersaturated before flashing (Q/K=1.45). This supersaturation may be the result of using down-hole scale inhibitors (due to

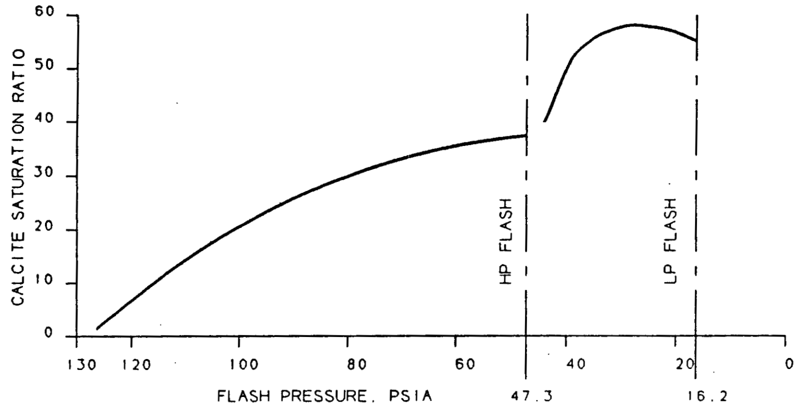


DUAL FLASH TEST 1: CALCITE SATURATION vs. FLASH PRESSURE

SATURATION CURVE BEFORE CALCITE DEPOSITION

SATURATION CURVE AFTER CALCITE DEPOSITION

Figure 2



GEM1 PLANT : CALCITE SATURATION vs. FLASH PRESSURE

Figure 3

de-gassing at individual wells), equilibrium with hydrated forms of calcite in lower temperature production wells, or mixing of fluids from different wells. In any case, it does not appear to be causing calcite precipitation. The test skid inlet fluid was slightly undersaturated (Q/K=0.96) due to fluid temperature decline through the wellbore and piping to the test skid.

The GEM 1 LP flash fluid is only about 10% more supersaturated than the test LP flash fluid (Q/K=55 vs. 50). With the loss of almost all noncarbonate CO_2 at the HP flash, the LP flash calcite saturation ratios are much closer in value. The dehydration of HCO_3^- to CO_2 generates most of the steam phase CO_2 in the LP flash, but, again, CO_2 was higher in concentration during the dual-flash tests, due to the lower LP flash steam fraction.

Bomb Test Results

Bomb tests evaluated the longevity of the Nalco product at concentrations of 3.4 ppm and 7.0 ppm, and the Monsanto product at 1.4 ppm. The concentration of calcium in solution declined significantly between 2 and 5 hours for all concentrations (Figure 4). After 4.6 hours the concentration of calcium in solution had decreased 52% (7.0 ppm inhibitor) and 54% (3.4 ppm inhibitor) with the Nalco product, but only 45% with the Monsanto product. More importantly, the calcium in solution continued to decline with both concentrations of the Nalco product, to minima of 19% at 7.0 ppm and 31% at 3.4 ppm, while the Monsanto product maintained a relatively constant calcium concentration (47%) up to 20 hours. Overall, the Monsanto product seems to delay calcite precipitation much more effectively than the Nalco product, especially considering the much lower concentration tested.

SUMMARY

Based on the inhibitor screening tests, the Nalco and Monsanto products are clearly superior to Betz and Drew products for inhibiting scaling in applications such as geothermal fluid production at East Mesa. Likewise, from the dual-flash tests it is clear that the Monsanto product at a concentration of 2 ppm is considerably more effective than the Nalco product at a concentration of 4 ppm. At the time of this publication the Monsanto product cost was 1.6 times greater than the Nalco product, making it the most-cost effective product tested. However, the corrosive nature of the Monsanto product increases capital costs for its feed equipment, and makes its use in down-hole applications very difficult.

The results of the screening test were repeated in the dual-flash test, suggesting that the former test, which is much faster and less expensive, can adequately reveal the relative effectiveness of various inhibitor chemicals. However, neither test procedure was able to mimic the actual plant conditions accurately enough to determine the absolute concentrations required for complete scale inhibition in the plant. Similarly, the lack of scale formation in the residence chamber does not reflect actual injection piping conditions; scaling in GEM 1 injection lines has occurred since start-up.

The bomb test results make it apparent that degradation of inhibitor performance will occur after injection. The Monsanto product delayed calcite precipitation longer than the Nalco product, and kept more calcium in solution.

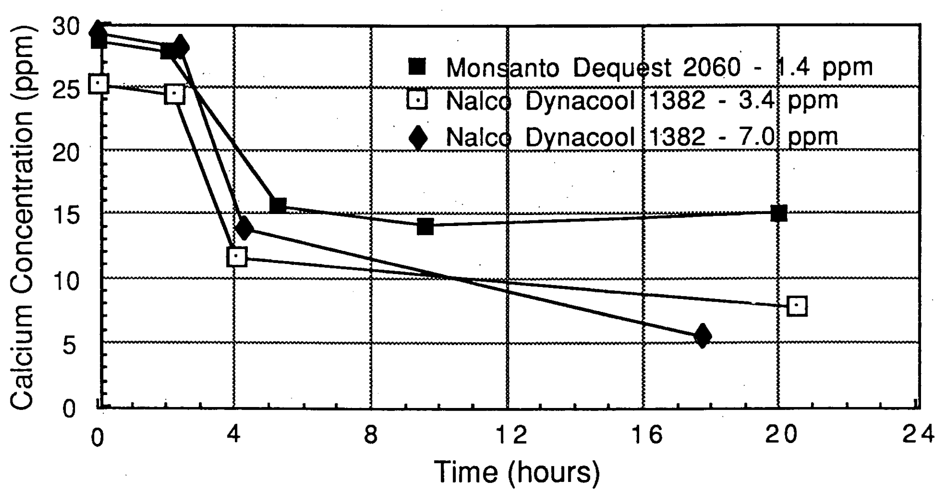


Figure 4 - Calcium concentration vs. time for laboratory bomb tests

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