CALCITE INHIBITION IN WELL SPQD
MINDANAO GEOTHERMAL PRODUCTION FIELD (MGPF), PHILIPPINES

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ABSTRACT

*A calcite inhibition system consisting of surface feed pumps and capillary tubing for down-hole injection was installed and operated for more than eleven months in well **SP4D**. The chemical inhibitor is an acrylate polymer which was continuously injected to attain a minimum dosage concentration of **5** mg/kg in the total discharge. Injection flowrate was maintained at an average **of 16 L/hr**. This give the inhibitor a residence time of about **45** minutes inside the tubing. The injection pressures are between **200** and **240 lbs/in^2**. The presence of a wellbore obstruction at **825** meters limited injection setting depth to **815** meters. Because of this constraint, **SP4D** was operated at high wellhead pressure to maintain flash point above the injection setting depth. Well bore simulators were employed to predict the flashpoint depth using available well data.*

*Decline in well head pressure, water flow and calcite saturation index **(CSI)** from September **1999** to March **2000** is consistent with progressive calcite deposition in the well bore. Drilling logs from subsequent work-over of the well show that majority **(–85%)** of the obstructions occurred below the injection depth where the inhibitor was absent. The lowering **of** the flash point below the injection depth is shown by presence **of** obstructions at **816-848** meters. Later analyses show that the basis for wellbore simulations were unstable initial discharge data and actual flash point depth occurs at deeper levels compared with the results **of** well bore simulations. In addition, calcite scales also developed at much deeper levels **(1275-1356, 1372-1384** and **7454-1460** meters) and cannot be related to variations in flashpoint depth. These deep scales were formed from cooler **(219°C)** calcite saturated fluids originating below **1460** meters and later heated by the hotter **(230-240°C)** fluids discharged from **1300-1305** meters.*

1.0 INTRODUCTION

Well SPQD (Figure 1) is one of two production wells in the Mindanao Geothermal Production Field (MGPF), which experience active calcite scale deposition. The well's recurring calcite deposition problem requires yearly work-over using a drill rig. After each work-over the discharge output of the well steadily declines with time thereby reducing generation profits. This prompted PNOC-EDC to conduct tests for long-term solutions to the calcite deposition problem in MGPF.

One proven method of preventing calcite deposition in well bores is through the injection of chemical inhibitors below the flash point of the well (Benoit, 1990 and Lovekin, 1990). **A** successful calcite inhibition program using this method has been successfully applied in geothermal fields in the USA, Japan, New Zealand and Costa Rica since 1988.

To test the feasibility of the method in MGPF, a calcite inhibition system (CIS) was installed on May 20, 1999, in well SPQD to **a** depth of 815 meters at high wellhead pressure condition. Well performance with the downhole injection system was monitored using geochemical and physical methods to evaluate the progress of the inhibition trial. On May **4,** 2000 after more than 11 months of inhibitor injection, the test was terminated because of continuously declining wellhead pressure and water flow.

This paper evaluates the physical and chemical data collected during the course of the inhibition trial. The performance of the well with the calcite inhibition system is assessed based on the current understanding of calcite scale formation phenomenon in well bores.

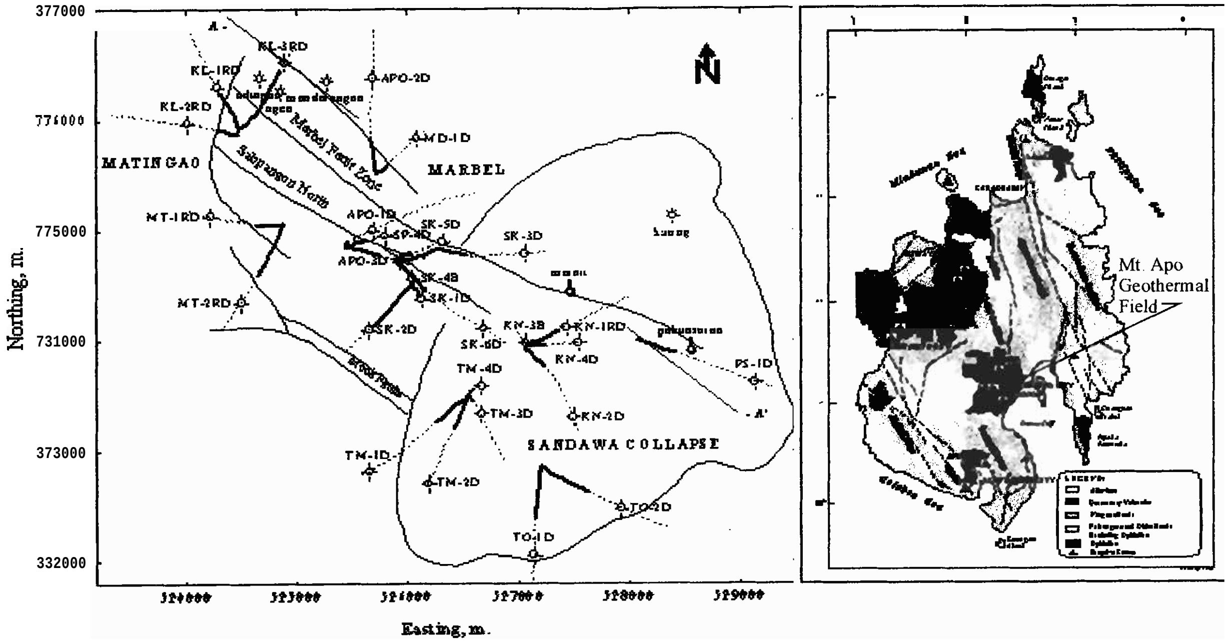

Figure 1. Mindanao Geothermal Production Field (MGPF) in southeastern Mindanao. Shown on the left are the structural features and drilled wells. Well SP4D is within the Marbel sector of the field.

2.0 REVIEW OF CALCITE DEPOSITION HISTORY OF SP4D

SP4D was put on commercial operation in March 1997. Nogara, et al. (1997) previously conducted a geochemical assessment of calcite blockage formation in wells APOID and SP4D. Initial assessment concluded that flashing of the SP4D fluid at around 230-235°C expels CO_2 gas, causing the fluid to increase in pH and calcite supersaturation. These chemical changes result in the deposition of calcite near or slightly above the flashpoint depth. Because of calcite deposition, SP4D discharge mass flow declines at a rate of 5.5 kg/s/month in 1997 (Ramos-Candelaria et al, 2000). The calcite saturation index (CSI) at the flash temperature range from 4 to 6 but eventually decline towards unity during periods of active deposition. Petrologic and x-ray diffraction analysis of calcite scales have for the most part 'platy' morphology. Calcite samples contain abundant liquid and vapor inclusions pointing to a boiling environment during formation. Homogenization temperatures (T_h = 238°C) of fluid inclusions from calcite scales agree with flash point temperature of the well (Duke et al, 2000). A work-over using drill rig was conducted in February 1998 to remove the calcite blockage and recover the previous output of the well.

After the work-over, SP4D was again put on commercial discharge in March 1998 with an initial output of 5.2 MWe. Another episode of calcite deposition occurred in the well. Massflow decline was estimated at 3.3 kg/s/month. The CSI of flashed fluid was initially from 3 - 5 but approached unity with progressive deposition. A second work-over was undertaken in April 1999 to remove blockages and prepare the well for the calcite inhibition system.

3.0 CALCITE INHIBITION SYSTEM (CIS)

A schematic representation of SP4D calcite inhibition system is shown in Figure 2. The system consists of surface feed equipment and the down-hole injection system installed through the wellhead. BuAing et al. (2000) discussed extensively the design considerations of the downhole injection set-up.

The surface feed system is made up of 2,000-L high-density polyethylene (HDPE) inhibitor solution tanks and 1/3-HP chemical dosing pumps. The injection system consists of a 0.25-inch outer diameter (inner diameter = 0.18 inch) capillary tubing weighted down with 54 kilograms of sinker bar and dispersion head set at a depth of 815 meters. A 3-inch stinger pipe is set above the master valve to prevent the

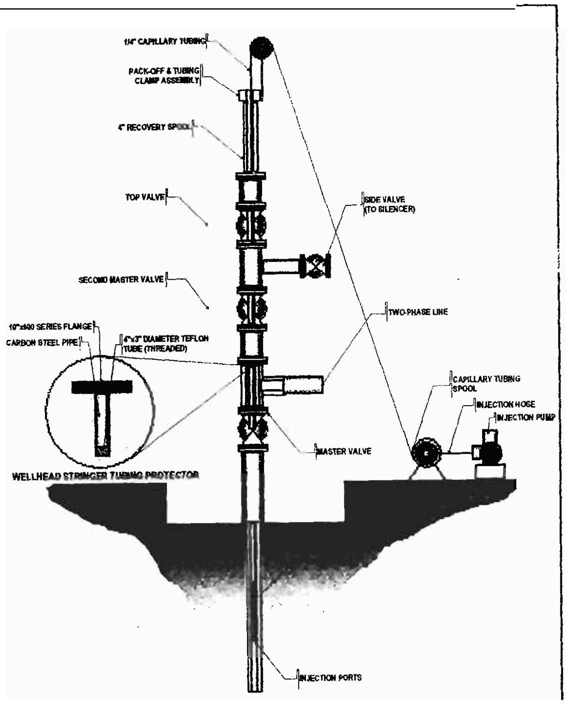

Figure 2. Above shows a schematic of the calcite inhibition system (CIS) installed in well SP4D.

tubing from being sucked into the production tee. To protect the tubing from rubbing against the stinger, Teflon tube was introduced at the bottom of the stinger. A stuffing box at the surface pack-off on top of the recovery spool prevents leakage of geothermal fluids to the environment. Braided Teflon is found inside the pack-off to protect the tubing from rubbing against the metal surface.

From the onset, installation of an ideal CIS was hampered by availability of only 1100 meters of capillary tubing and the presence of an obstruction presumed to be a casing break at 825 meters. When the well is fully open with a wellhead pressure of about 8.0 kg/cm^2 the expected flashpoint depth is at 940 meters. Because of these limitations, it was agreed to raise the flashpoint depth level above the blockage depth so that the field-testing of the calcite inhibition system in SP4D can proceed. Throttling the well through the production isolation valve raised the wellhead pressure. Table 1 shows the expected flashpoint depth of the well at varying wellhead pressures. The flashpoint depth was calculated using a commercial wellbore simulator.

Table 1. Expected flashpoint depths of the well at varying wellhead pressure (WHP) and Total Mass flow (TMF) calculated from bore output data before CIS installation.

WHP Kg/cm^2 (gauge)	TMF (Kg/s)	Power (MWe)	FP Depth (Meter)
8.0	69	5.8	940
8.4	64	4.7	890
10.0	53	3.8	850
10.5	48	3.3	730
10.8	45	3.0	700
11.4	40	2.6	550
12.0	35	2.2	500

For an effective inhibition, the chemical inhibitor has been dosed traditionally about 100 meters below the flash point (Benoit personal communication, 1999). Using this as a guide, the flashpoint depth required would have to be at or above 715 meters since the dispersion head of the CIS was placed at 815 meters. This means that the corresponding wellhead pressure must be at or above 10.8 kg/cm^2 (gauge). As an added precaution against possible lowering of flashpoint depth, it was agreed that the operating wellhead pressure would be maintained at above 12.5 kg/cm^2. The drawback however is that the discharge output of the well was greatly reduced to less than 35 kg/s.

A 5% solution of Nalco 9354, an acrylate polymer was injected at a flow rate of 14-17L/hr to achieve a minimum dosage concentration in the total mass flow at least 5 mg/kg. The dosing pump injection pressures were stable at 200-240 lbs/in^2 during the test. The residence time of the inhibitor from time of injection until discharge to surface is 45 minutes at an injection rate of 17 Uhr.

4.0 MONITORING THE TEST

Various geochemical and physical parameters were monitored during the inhibition trial. Physical parameters monitored included: well head pressure (WHP), weight of down hole injection system, injection pressure of dosing pump, bore output (waterflow, steamflow and enthalpy) of the well, simulated flash point depths and inhibitor injection flow rates. Geochemical parameters monitored included: water and steam chemistry, calcite saturation index (CSI), and inhibitor concentration. The results of monitoring for weight of downhole system, pressure of dosing pump, inhibitor injection flow rate, and inhibitor concentration were stable and remained unchanged throughout the duration of the test. Results of these monitoring are not presented and discussed in this paper.

4.1 WHP and Mass Discharge Output Monitoring

Monthly bore output measurements were planned for SP4D to monitor the progress of inhibition. These measurements were to be done using either the Silencer Lip Pressure Method (JLPM) or Tracer Flow Tests (TFT). However because of operational constraints, only four silencer tests and one TFT were conducted during the test period. Despite the lack of bore output data from these two modes of measurements a total of 30 sets of waterflow data were obtained using sodium benzoate tracer dilution method.

As observed in SP4D, maintaining a stable wellhead pressure at throttled condition is problematic. From the onset of the test, it was observed that WHP vaned considerably and tends to decrease through time. No explanation was available in the early stage of the test to exptain this behavior. To maintain the WHP requirement set before the test (>12.5 kg/cm^2) the well opening was continuously adjusted through the production isolation valve (PIV). This procedure is shown in the topmost plot of Figure 3. Shown in the plot are the well openings of SP4D throughout the test in terms of PIV valve travel measured in inches. Longer valve travel translates to smaller well opening while shorter valve travel means larger opening.

SP4D underwent five well opening adjustments during the course of the test. These adjustments are shown to be effective in maintaining the WHP of the well (Fig. 3) above the threshold limit. However, adjusting the opening of the well causes waterflow to vary. The trend of massflow or waterflow is considered the parameter that would give a definitive indication of the success of the inhibition system. Changing well openings would confuse the results of waterflow monitoring. To remedy this problem, the PIV valve travel was maintained at 1-1/8 inch from September 1999 to February 2000.

During this period waterflow decline became apparent with an estimated average decline rate of 3.3 kg/s/month. This decline rate is similar to that recorded in 1998 after the first work-over of SP4D (Ramos-Candelaria et al., 2000). From initial water flow of 30 kg/s in September, the water flow dropped to 21 kg/s in February 2000 to 16 kg/s in March 2000. Finally, in May 2000 the well was put into horizontal silencer discharge for another bore output test but was unable to sustain discharge (Trazona, 2000).

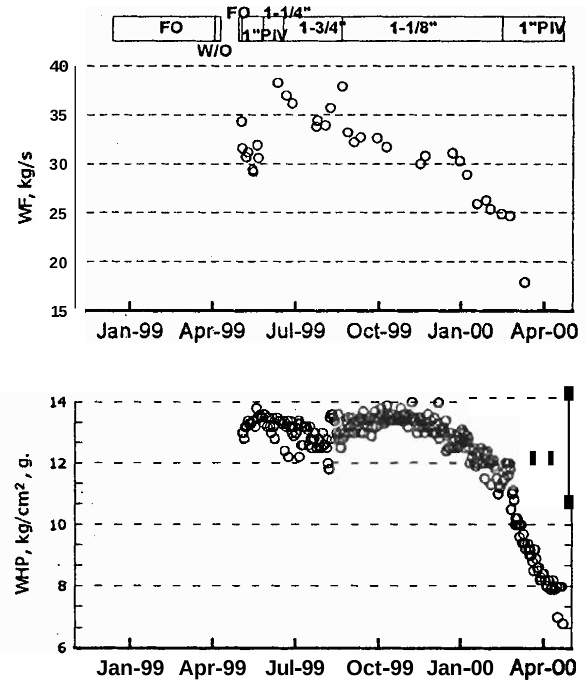

Figure 3. Bottom plot shows the behavior of wellhead pressure (WHP) and water flow (top) of SP4D during the test. Topmost bar graph indicates the production isolation valve (PIV) opening at different times.

4.2 Flash Point Depth Monitoring

The flash point depth of the well was calculated Using HOLA wellbore simulator using the updated waterflow and WHP data. The plot of flashpoint depth and measured waterflow through time are shown in Figure 4. In the calculation, the discharge enthalpy is based on the latest bore output measurement of the well.

The updated data suggests that in the initial four months, flash point levels are already below 800 meters. Later analyses show that basis for wellbore simulations were unstable initial discharge data and actual flash point depth occurs at deeper levels as compared to the results of the initial well bore simulations before CIS installation.

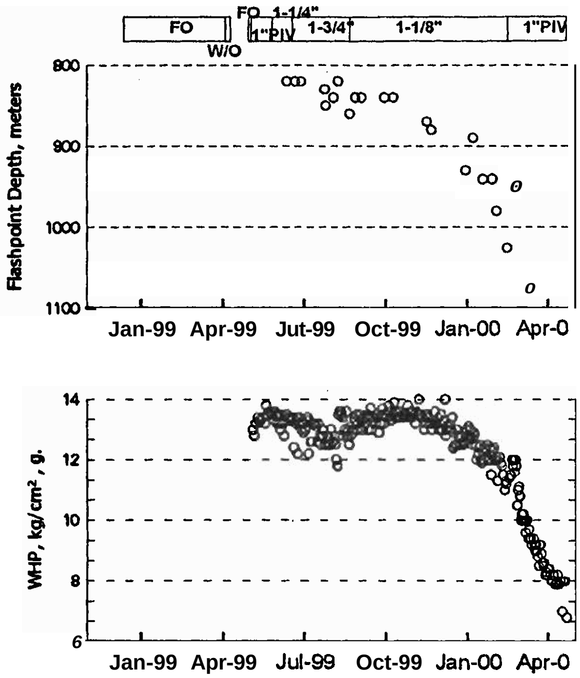

Figure 4. Calculated flashpoint depth *of* SP4D based on water flow and wellhead pressure data.

Waterflow data in September **1999** shows further deepening of flash point depth lower than **815** meters and as deep as 1100 meters. However, this phenomenon can only occur if the well experienced large pressure drawdown at a rapid rate or if the major feed zone at **1200** meters ***is*** blocked. The latest pressure survey shows only minimal pressure drawdown (–0.5 bars). **Also,** there were no obstructions tagged at the major feedzone of the well (Table **2).** Furthermore, the behavior of the flashpoint depth suggests that with enhanced deposition, the scales should form from shallow level (close to 800 meters) then progressively to deeper levels until 1100 meters. However, obstructions encountered during work-over are confined to the initial flash point depth, and then the well bore **is** clear until much deeper level obstructions are encountered from **1275** meters to bottom. ***This implies that flashing only occurs at shallow levels near 875 meters.*** A more rigid calculation might be needed to fully simulate the behavior **of** the flashpoint when obstructions such **as** calcite scales already modified the diameter of the well.

Prior to the run-in of the CIS last May **1999,** the downhole tools tagged an obstruction at **825-830** meters during one **of** the routine flowing surveys. This obstruction was later identified as calcite remaining from recent work-over. An obstruction in a well bore with hot fluids flowing will cause a change in phase or flashing (throttling effect) of the flowing hot fluids. Perhaps this enhanced the deposition at **816-848** meters.

Table 2. Feed zone contributions *of* SP4D at two wellhead pressures based on flowing PATS surveys

PARAMETER	THROTTLED	FULLY OPEN
WHP, kg/cm^2(g)	13.4	11.0
TMF, kg/s)	34.7	57.5
Enthalpy, J/g	1065	1046
Flashpoint, m.	760-770	790
FEEDZONE. m.	FLOW. ka/s	FLOW. ka/s
810-815	2.1	5.7
1200-1205	16.3	27.2
1300-1305 & 1445-1450	16.3	24.6

Despite the lowering of flashpoint depth through time, the level of flashing did not reach to depths below **1275** meters. Flashing therefore could not account for the presence of calcite deposits below **1275** meters. Since fluid entering the major feedzone of the well at **1195-1200** meters are at saturated condition, flashing may not proceed to lower levels. There must, therefore, be other mechanism of calcite deposition occurring below this depth. It has been characterized before that a minor feedzone exists below **1460** meters that discharge fluid at a lower temperature **(–219°C)** compared to the feedzones at **1300-1305** meters which has a feed temperature between **230-240°C.**

4.3 Geochemistry Monitoring

Twice monthly water and steam samples from SP4D were collected during the course of the inhibition trial. Time plots of chloride, calcium and carbon dioxide concentration of the well fluid calculated to total discharge, silica geothermometer temperatures ($TSiO_2$) and calcite saturation index are plotted in Figure ***5*** together with waterflow for reference. Stable chloride was observed starting first week **of** July **1999.** This is consistent with fluctuating waterflow measurements in the initial period of May-June **1999.** This suggests that output of the well was not stable in May **2000.** Stable chloride values from July **1999** to March **2000** shows the same supersaturated reservoir fluid is entering the well. An average $TSiO_2$ of **239°C** was maintained, attesting to the absence **of** any cold fluid inflow.

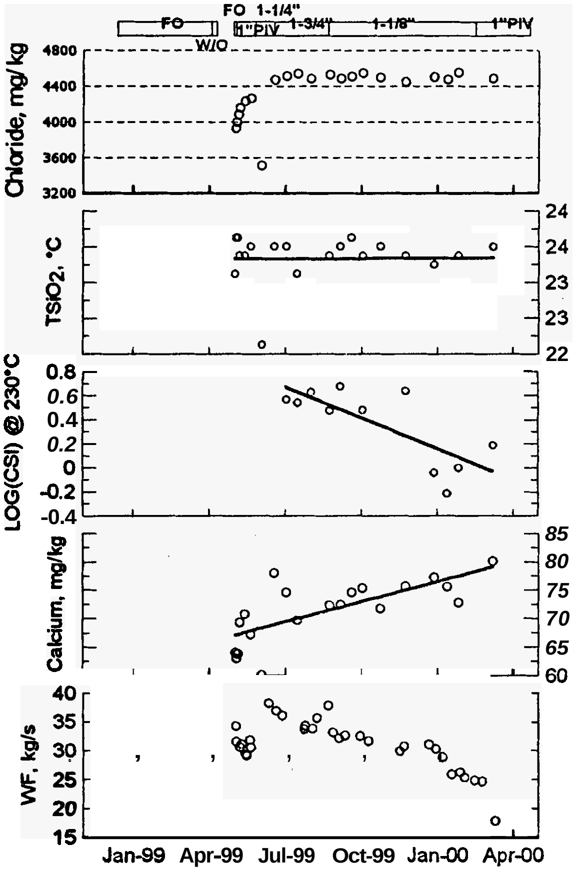

Figure 5. Above plots shows the trends of geochemical parameters through time in relation to change in water flow. The third plot from the bottom shows the calcite saturation index of the fluid after boiling at 230°C (refer to text for discussion).

Calcium values showed an apparently increasing trend (60-80 mg/kg) with an average value of around 70 mg/kg. Even in the period September to March, calcium values do not exhibit any significant declining trend expected during calcite scale formation. This is indicative that calcium alone cannot be used to monitor either deposition or inhibition.

The calcite saturation index (CSI) of the fluid is calculated using the WATCHWORKS chemical speciation software (Klein, 2000; Arnorrsson and Sigurdsson, 1982). The CSI monitoring shows two distinct values of CSI, those that are above unity (indicative of over-saturated condition) and those that are equal or below unity (indicating equilibrium or saturated condition). CSI values above 1 appear throughout the inhibition trial (May-December, 2000) where deposition is absent as inferred from waterflow data. Points below or close to unity appear only in the latter stages when massive deposition (Jan-March, 2000) is presumed to be occurring.

Uniformly high CSI can be used as indication of the high scaling potential of the fluid during successful inhibition and possibly the absence of scaling. However, when this initially high value is not maintained, then successive lowering of CSI value is already indicative of a fluid dispensing of excess dissolved calcite (deposition). The CSI is a useful parameter in calcite scaling, but it may not be as sensitive as water flow measurement to denote the onset or progress of scaling as seen from the time lag between decline of waterflow and decline of CSI.

5.8 POST WORK-OVER BLOCKAGE ANALYSIS

Because SP4D cannot sustain its discharge after in March 2000 the calcite inhibition test in the well was terminated. After pullout of the capillary tubing the well was worked-over using drill rig in May 2000. The drilling log during work-over is presented to determine the location of calcite deposits of the well during the test.

SP-4D has undergone three mechanical work-overs using drill rig to remove calcite blockages. The first work-over was done in February 1998, the second in April 1999 and the last after the inhibition trial in May 2000. Table 3 shows the pertinent well bore casing summary, and obstruction data as tagged by a 6 ¼" drill pipe during the workovers.

Table 3. Well bore casing summary of SP4D and the tagged obstructions during workover of the well

HOLE CASING SUMMARY			
Type	Hole Size inches (mm)	Casing Size, inches (mm)	Depth, meters
Surface	26(660)	20(508)	47.4
Anchor	21(533)	13 3/8 (340)	175.8
Production	12 ¼ (311)	9 5/8 (245)	739.7
Slotted Liner	8 ½ (216)	7 5/8 (194)	
Top of *Liner*			729.3
Bottom of ***Liner***			1480.7

Obstructions Tagged During Workover			
Year	1998	1999	2000
Depths	610-805 1309-1333 1423-1472	786-846 1218-1246 1312-1379 1408-1472	730-754 816-848 1275-1356 1372-1384 **1454-1460**

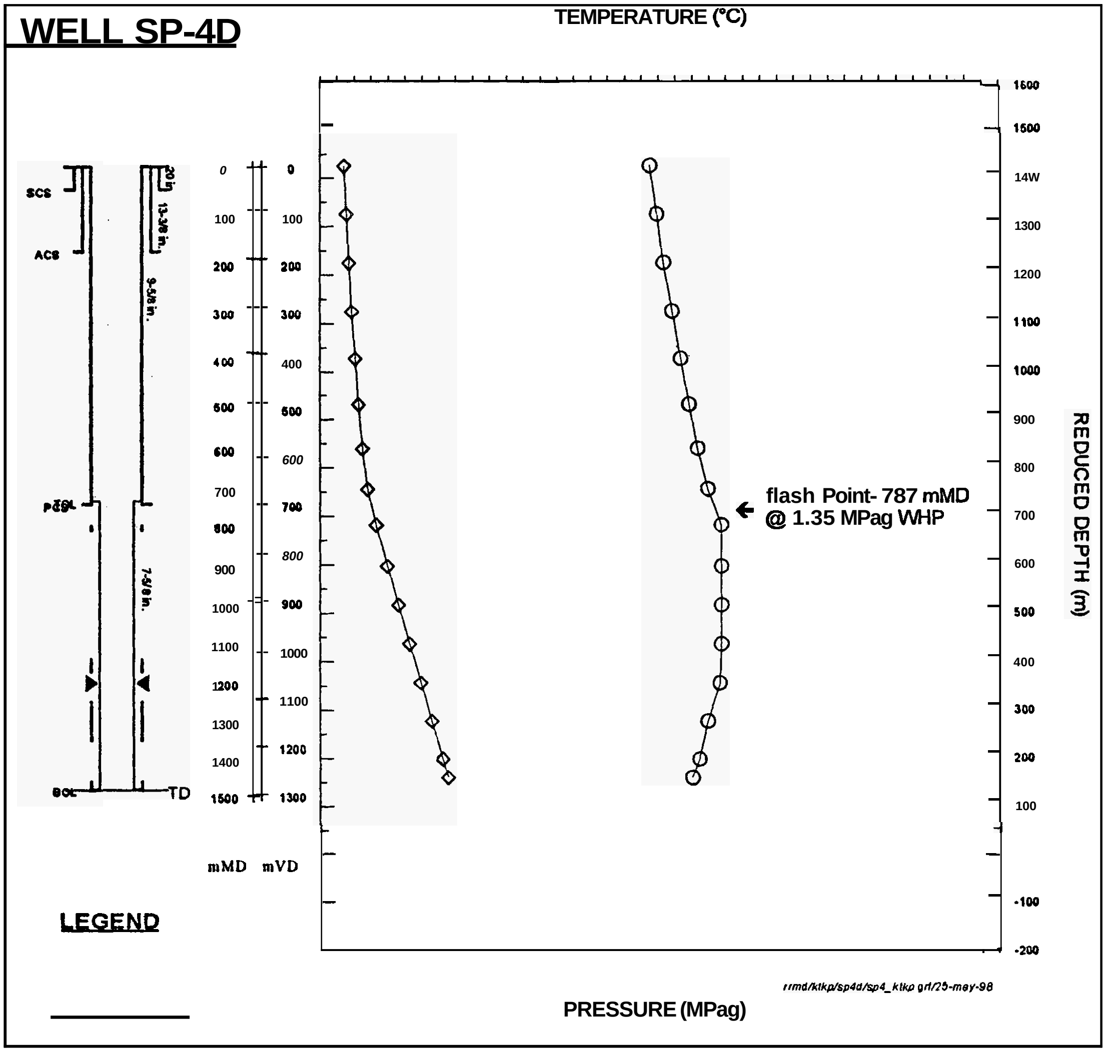

Figure 6. The **above** plot shows the latest downhole pressure and temperature profile of SP4D. **Also** shown are the feed horizons of the well.

The obstructions from the **1998, 1999** and **2000** clean outs occur in two portions of the well bore, those that are tagged at shallow zones close to the flash point depth of the well (~790-800 meters) at fully open discharge conditions and those at deeper zones (from **1200** meters to bottom). The formation of calcite scales at these depths is consistent and appears to be recurring every time the well is discharged.

Shallow obstructions encountered in the 2000 work-over occur in two places at **730-754** meters, just above the **CIS** injection depth at **815** meters and below at **816** to **848** meters. Deep obstructions occur at **1275-1356, 1372-1384** and at 1454-1460 meters. Majority **(85%)** of the tagged obstructions are below the injection depth, where the inhibitor is absent.

The presence of obstruction at **730-754** meters is puzzling since these formed **52-63** meters above the injection depth and where inhibition should have been in effect. It is likely that this obstruction is related to change in well bore configuration close to the top of liner at **729** meters and not calcite scales as previously suspected.

Although flash point depth calculations shows that flashing occurred in the well just above 1100 meters towards the end of the test, this does not justify the presence of calcite scales at **1275** meters and below. It is believed that these deep scales in **SP-4D** are formed from mixing of cooler fluids **(219°C)** from 1460-bottom and being heated by the hotter fluids **(230-240°C)** from **1300-1305** meters (Figure **6).**

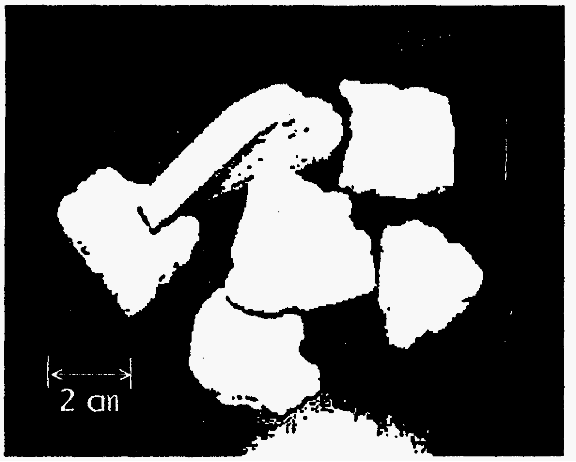

Figure 7. Samples of calcite scales from SP4D post-workover discharge debris. Note the pronounced curvature of the scale hinting at the shape of the scaled surface (refer to text for discussion).

6.0 PETROLOGY OF SCALES

Blockage samples taken by scraper from shallow obstructions (628-781 meters) in 1997 and 1998 in SP4D are described as consisting mainly of calcite with subordinate amounts of aragonite and smectite (Duke, et al, 2000). The scales contain liquid and vapor fluid inclusions suggesting deposition from two-phase fluid. Homogenization temperature (Th) of fluid inclusions from the calcite scale is about 230°C. This more or less coincides with the flashpoint temperature of the well from flowing surveys and wellbore simulation.

Post work-over vertical discharge of SP4D presented an opportunity to collect debris from cleaning of well bore obstructions. Debris collected from well during vertical discharge in June 2000 consists mainly of white calcite crystals forming layers with thickness of 9-17 millimeters (Figure 7). The curvature of the calcite deposits conforms to an inner casing diameter of 7-1/8 inches consistent with the inner diameter of the 7-5/8 inch slotted liner. All the scales collected are exclusively related to the 7 5/8" slotted liner confirming drilling log results that obstructions are not present in the 9-5/8 inch casing. The scales collected contain abundant minute fluid inclusions in planar array. Both liquid rich and vapor rich inclusions are present indicating deposition from flashing fluids. The homogenization temperature from large inclusions is at 240°C (Zaide-Delfin, 2000) similar to 1998 results. The petrologic data suggest that recovered scales may have been from the shallow zone where flashing is known to occur.

Assuming that all the tagged obstructions are calcite scales, then the whole length of scaled portion is 156 meters. If it is assumed that a uniform scale thickness of 13 millimeters (average between 9 and 17 mm) adhered all the way through 156 meters of slotted liner, then the total calcite scale produced in the eleven months of discharge is about 2.2 m^3. The estimated total mass output of the well during the test is 800,000 tons of fluid. This puts the calcite yield of the fluid at 2.8E-4 cm^3/kg. Incidentally, the estimated calcite yield of the fluid based on geochemical simulations is in the order of 4.8E-4 cm^3/kg.

Although it was expected that the morphology of the scales coming from 1275 meters down to bottom would be different from that formed at 816-848 meters, this was not confirmed. This was due mainly to the absence of such scales among those collected from the discharge debris.

7.0 CONCLUSIONS

A simple calcite inhibition system composed of surface feed pumps, down hole injection using %-inch capillary tubing and Teflon protected stinger near the well head was successfully installed and operated for more than 11 months (May 20,1999 – May 4,2000) in well SP-4D.

The presence of a well bore obstruction at 825 meters limited injection setting depth to 815 meters. Due to this constraint, SP-4D was operated under high wellhead pressure conditions to maintain flash point depths to shallow levels.

Declining trends in calcite saturation index, wellhead pressure and waterflow with time from September 1999 to March 2000 under constant wellbore opening is clearly consistent with progressive calcite deposition in the well bore. Work-over ***drilling logs confirm that majority (85%) of blockages occurred at deep levels beyond the injection depth.*** The lowering of flash point depth below the inhibitor injection depth from wellbore modeling calculations is confirmed by presence of calcite scales with abundant vapor inclusions tagged during drilling work-over at 816-848 meters.

Aside from calcite scale formation due to flashing, obstructions at much deeper levels (1275-1356, 1372-1384 and 1454-1460 meters) are inferred to be calcite derived cooler (219°C) and calcite-saturated fluid at 1460-bottom, being heated by the hotter (230-240°C) fluids from 1300-1305 meters.

The presence of tagged obstructions at 730-754 is related to change in well bore configuration close to the top of liner of the well at 729 meters. Calcite inhibition system effectively prevented the formation of calcite scales above 815 meters.

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