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CALCITE DEPOSITION IN TWO-PHASE LINES IN BACMAN GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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ABSTRACT

Wells OP-5DA and OP-6D supply geothermal two-phase fluids via 457 mm diameter individual branch lines to a 20 MWe power plant in the BacMan geothermal production field, Philippines. These fluids mix in a 610 mm header before mixing with similar fluids from other wells. The resulting two-phase mixture passes through a vessel where steam and liquid separates. After about six months of field operation, the wellhead pressures of OP-5DA and OP-6D simultaneously increased, approaching pipe design limits. All available data show the presence of a blockage although its location could not be ascertained while the wells were supplying fluids.

During inspection while the power plant was shut down, voluminous calcite deposits were observed. These deposits nearly sealed the two-phase header at the portion where OP-5DA and OP-6D fluids mix. Thin calcite laminates were found only in the bottom portion of OP-5DA branch line. In contrast, OP-6D branch line was free of deposits inasmuch as its discharge is pure steam.

Heat and mass balance calculations and calcite simulation studies using WATCH and CHILLER programs were done to investigate the processes involved, formulate a model to explain the deposition and propose recommendations to handle the situation.

1. INTRODUCTION

One of the most common production problems in geothermal fields is calcite (calcium carbonate) scale deposition. Calcite blockages formed in the wellbores decrease significantly the output of the production wells. Calcite scaling is experienced in almost all the geothermal fields around the world, i.e. in the Dixie Valley geothermal field, Nevada (Benoit, 1989), in Ohaaki geothermal field, New Zealand (Clotworthy et al., 1995 and Nogara, 1999), in Seltjarnarnes geothermal field, Iceland (Kristmansdottir et al., 1995) and in Coso geothermal area in California (Evanoff et al., 1995). In extreme cases, most of the production wells and surface facilities in the Kizildere geothermal field in Turkey were blocked by calcite scale and serious generation losses were incurred (Durak et al., 1993). Todaka et al., (1995) also reported calcite deposition, together with anhydrite (calcium sulphate) in the wellbores in Oguni geothermal field in Kyushu, Japan. Like other geothermal field, the BacMan geothermal production field is not an exception with regards to the problem of calcite scaling. The formation of calcite deposits in the two-phase pipelines in BacMan have not been observed in any other Philippine production wells.

The BacMan Geothermal Production Field is located on the southern portion of the island of Luzon, Philippines (Fig. 1). The first power plant commissioned in 1993, was the 110-MWe BacMan-I in the Palayang Bayan sector. The 20-MWe BacMan-II modular power plant in Cawayan sector was commissioned in 1994. Another 20-MWe BacMan-II modular power plant in Botong sector was commissioned in March 1998.

Four-production wells (OP-3D, OP-4D, OP-5DA and OP-6D) supply steam to the Botong power plant (Fig. 2). OP-5DA and OP-6D supply two-phase fluids via 457-mm diameter individual branch lines. These fluids mix in a 610-mm header before finally mixing with fluids from OP-3D and OP-4D. The resulting two-phase mixture passes through a vessel where the steam and liquid are separated.

After about six months of operation, in late September 1998, the wellhead pressures of OP-5DA increased slightly. Then, by late October 1998, a similar increase was observed in OP-6D. By December 1998, the pressures in both wells increased significantly that they approached pipe design limits. (Fig.3)

All available data show the presence of a blockage although its location could not be ascertained while the wells were supplying fluids. Pressure measurements along the two-phase lines revealed that the constriction is near the confluence of OP-5DA and OP-6D at the 610-mm diameter two-phase line header (Fig. 4). The wells were alternately by-passed in order to relieve line pressure. Thereafter, the plant was shut down on February 5, 1999 to allow inspection of the pipes.

The inspection revealed voluminous calcite deposits that nearly sealed the header at the portion where OP-5DA and OP-6D fluids mix (Fig.5). Thin, platy calcite laminates were also found but only at the bottom portion of OP-5DA branch line. In contrast, OP-6D branch line was free of deposits inasmuch as it was discharging pure steam. Physical and chemical simulation studies were conducted to investigate the processes involved, to formulate a model to explain the deposition and propose recommendations to handle the situation.

2. PHYSICAL SIMULATION

Bore output measurements (BOM) of OP-5DA and OP-6D were used to simulate the physical condition of the mixed fluid at the 610-mm diameter two-phase header. The simulation utilized a hydraulic model to calculate for all the fluid properties based on the steam table, an energy balance for fluid mixing, and pressure changes along the pipe calculated using the Dukler correlation for two-phase fluid and the Darcy method for single-phase fluid. The flow regimes and the gas-liquid partitioning in the pipe were determined using the modified Baker method and the Eaton correlation, respectively (Bondoc, 1999, pers. comm.). The results of the physical simulation are tabulated in Table 1.

3. CHEMICAL SIMULATION

The WATCH (Bjarnasson, J.O, 1994) and CHILLER (Spycher and Reed, 1990) programs are used in rock-liquid interactions. Both programs take in chemical analyses of liquid, gas, and steam condensate samples with the pH, temperature and pressure at the sampling point. At any desired temperature, the program calculates the pH, aqueous speciation, partial pressure of gases, redox potentials, ionic strength, activity coefficients, chemical equilibria and mass balance equations to get the fluid composition and distribution of mineral species. In addition, CHILLER can handle fluid mixing as well as quantify deposits.

In this study of scaling potential, both programs were used to compute the fluid composition of samples taken at the branch line (170°C) after it had undergone adiabatic boiling (flashing) while in transit from the reservoir. Two reservoir temperatures were used based on changes in the well discharge characteristics (as different feed zones interplay during the two-phase discharge). From February to July 1998, the well was producing from a reservoir feed zone at 281°C. On the succeeding months, where the highly mineralized and hotter fluid (300°C maximum) started to inflow, feed temperatures averaged 294°C. Thereafter, flashing temperatures used were 170°C at the branch line and 167°C at the header. The branch line temperature was derived from the physical simulation while the header temperature was obtained from fluid inclusion (FI) analysis of a calcite crystal collected at the header which may represent the maximum temperature drop inside that section.

4. DISCUSSION OF RESULTS

Calcite may form from hydrolysis (involving replacement of calcium alumino silicates), boiling (from fluids having high dissolved carbon dioxide concentrations and in the absence of mineral pH buffer) and heating of cooler peripheral fluids (Simmons and Christenson, 1993). In a boiling environment, 'platy' calcite precipitates in open spaces upon loss of carbon dioxide with the carbonate species mostly controlling the pH and is described by the reaction:

$$2HCO_3^- + Ca^{++} = \text{calcite(s)} + H_2O + CO_2\text{ (g)} \quad \text{.......... (1)}$$

While most of the carbon dioxide is evolved at the first flash (probably due to a large gas distribution coefficient), the reaction does not always proceed to completion to the right (Todaka et al., 1995). Thus, there are always components available for deposition as the fluid travels from the wellbore to the surface.

Simulation of OP-5DA two-phase fluid under a single-step boiling showed undersaturation in February 1998 and increasing calcite oversaturating with time, peaking in November 1998 (Fig.6) before lowering (but still oversaturated) by December 1998. In the branch line, calculated log (Q/K) for calcite ranged from - 2.44 (February) to + 1.70 (November). With a similar trend, log (Q/K) for calcite at the header ranged from –2.31 to +0.99. The decline in the oversaturation at the header can be attributed to the increased solubility of calcite with decreasing temperature (Todaka, et al., 1995). It may also suggest a significant, but not a total, loss of calcium from the fluid due to deposition before reaching the header. If such is the case, the calculated log (Q/K) for calcite may represent only the minimum oversaturation. From a meter upstream of the production isolation valve (PIV) until the header tapping, thin 'platy' calcite was found. This indicates that the fluid in this section of the OP-5DA branch line (nearly 15 m long) was boiling (Eqn. 1).

The liquid phase of OP-5DA underwent additional flash or boiling by as much as 5% average (range 1.1-12%) upon mixing with the steam discharge of OP-6D (superheated by 16°C) at the header (Table 1). The flashing resulted in the concentration of OP-5DA liquid phase by 43% average (range up to 12.5-75%). The December 1998 data showed that the liquid phase was oversaturated in all sections of the FCDS. The simulation gave a maximum liquid phase decline of 75% with an additional flash of only 3% (from 4% liquid phase fraction in the branch line to only 1% at the header) upon mixing with the superheated steam from OP-6D. This significant loss of volume is due to the inherently small liquid phase fraction in the two-phase fluid of OP-5DA. The branch line only had 17 mg/kg calcium but gave the highest concentration of calcium at about 1700 mg/kg by the time the liquid phase reached the header. This is a result of direct liquid vaporization, as opposed to mixing prior to flashing, caused by mixing with superheated OP-6D fluids. While there is a significant, but not total, loss of Ca due to deposition before the liquid phase reached the header, the additional flash of OP-5DA liquid phase (by only 3%) due to heat transfer from OP-6DA exacerbated the oversaturation of the fluid with respect to calcite. The form of calcite is voluminous in the header. It is the oversaturated liquid fraction in OP-5DA mixing with the superheated OP-6D fluid that caused the deposition in the header.

In contrast, the February 1998 Ca in the OP-5DA branch line was 18 mg/kg (Table 1). This increased to 260 mg/kg at the header after the fluid boiled by 12% and effected a concentration of the liquid fraction by 41% (from 17% at the branch line to 7% at the header). Despite this additional flash, the fluid in all sections of the FCDS was undersaturated with respect to calcite. Under conditions where OP-6D discharge is not superheated (as in June 1998 data), additional boiling of OP-5DA fluid by at least 1.1% still occurs at the header and concentrating the liquid fraction by as much as 12.5%. This is enough for the fluid to oversaturate with respect to calcite even if the fluid enthalpy of OP-6D (2641 kJ/kg) is similar with OP-5DA (2600 kJ/kg).

Although calcite deposition was observed in the branchline and header, presently no evidence of calcite blockage was detected in the wellbore of OP-5DA. This is shown by the increased two-phase flow rate in the December 1998 BOM data (14.8 kg/s) compared to the February (14.3 kg/s) and June (12 kg/s) data (Table 1).

Other physical factors such as pressure drop and flow regime may contribute to the formation of calcite. Simulated pressure values, however, indicate negligible pressure drop (0.01 bara) from the branch line to the header. The most significant pressure drop is from the wellbore to the branch line. While the simulated flow regime in OP-5DA wellbore is annular, it is wave in the horizontal branch line and at the header (Table 1). This wave flow is attributed to gravity acting upon on the horizontal pipe section resulting in the phase segregation of the liquid and vapor phases. This was confirmed upon pipe inspection at branchline where calcite deposition was observed only at the bottom section of the pipe. Hence, the wave flow regime was more significant to the formation of calcite along the branch line portion than at the wellbore.

5. CONCLUSIONS

a. OP-5DA reservoir fluid is oversaturated with respect to calcite.

b. The effect of pressure drop from the OP-5DA branchline to the header was very minimal in the formation of voluminous calcite deposits.

c. The mechanism for the voluminous deposition of calcite at the 610-mm diameter header was significantly attributed to the declining liquid fraction of OP-5DA discharge and further concentration through additional boiling upon mixing with the superheated steam discharge of OP-6D.

d. The phase segregation of the liquid and steam phases along the horizontal pipe portion further induced calcite deposition, since CO_2 is evolved during the process.

There are a number of possible options that can be implemented to address the effect of voluminous calcite deposition in the branchline and header. These options are now being studied. Durak, et al., (1993), Evanoff et al., (1995), Todaka et al., (1995) and Candelaria (1999) have reported similar problem but mostly inside the wellbore. They commonly employed injection of polymeric anti-scalant additives (e.g. polyacrylic acid, polymethacrylic acid, polymaleic anhydride), conduct mechanical wellbore cleaning, and use of acid to remove the scales. Because of the cost involved in the application of anti-scalant additives (Kellogg and Moffat, 1998) and the use of acid, the following options are considered:

a. Remove the liquid fraction in OP-5DA using a modified 610-mm diameter concentric drain-pot.

b. Install a spooled by-pass along the 610-mm header and conduct periodic mechanical cleaning.

c. Install a U-shape separator along the 457-mm branchline to collect the liquid fraction in OP-5DA.

d. Install a 610-mm or a 1067-mm diameter spool along the 610-mm diameter two-phase header and allow the calcite to deposit and conduct periodic mechanical cleaning.

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Fig.1 BacMan Geothermal Production Field Location Map

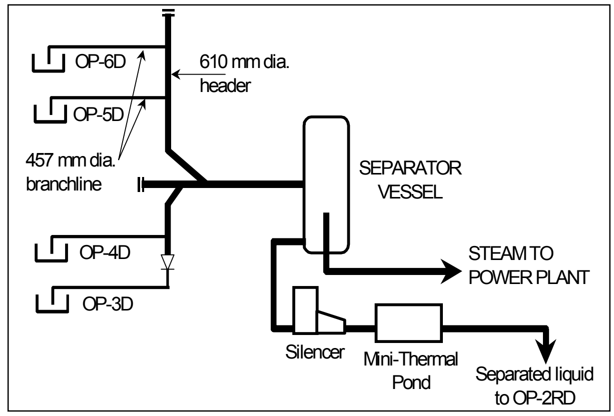

Fig.2 Botong Fluid Collection and Disposal System (FCDS).

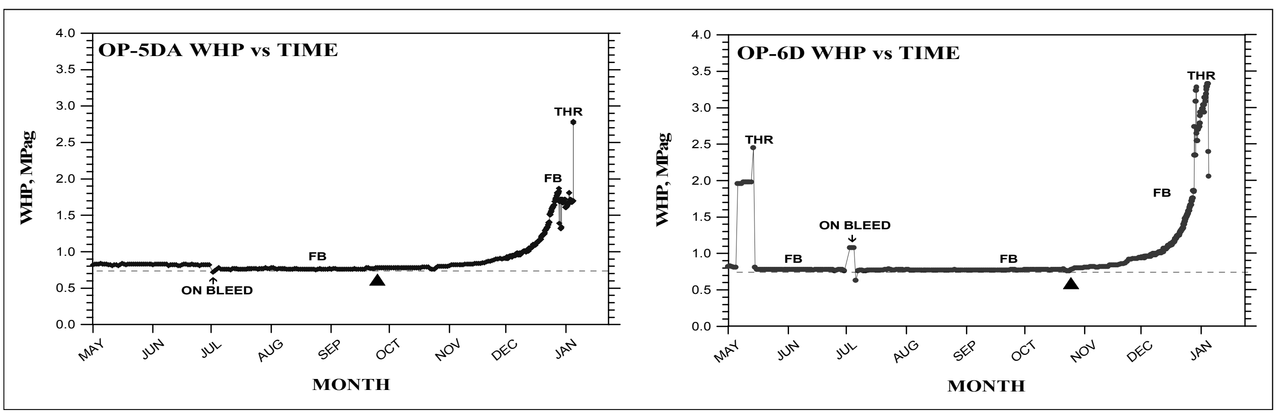

Fig.3 OP-5DA & OP-6D WHP vs. Time.

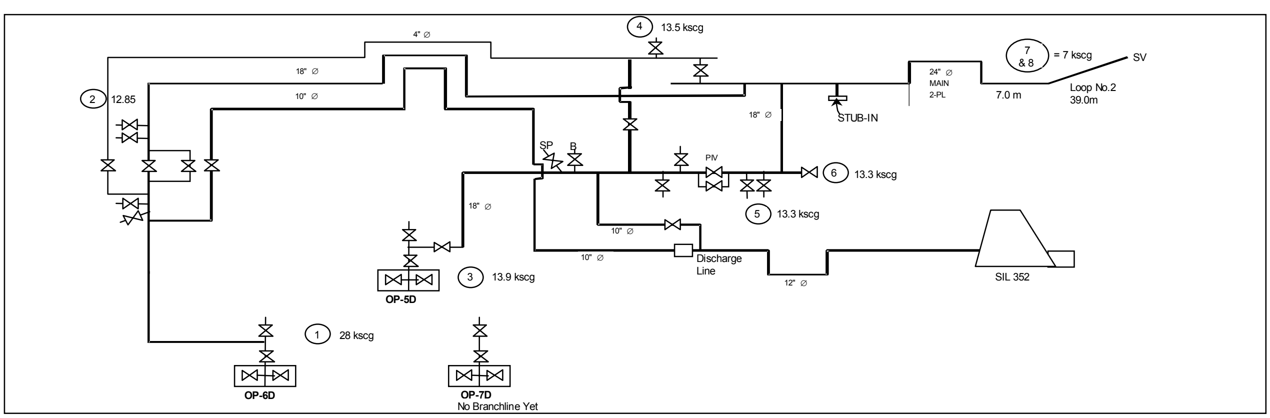

Fig.4 Pressure measurements along the two-phase lines.

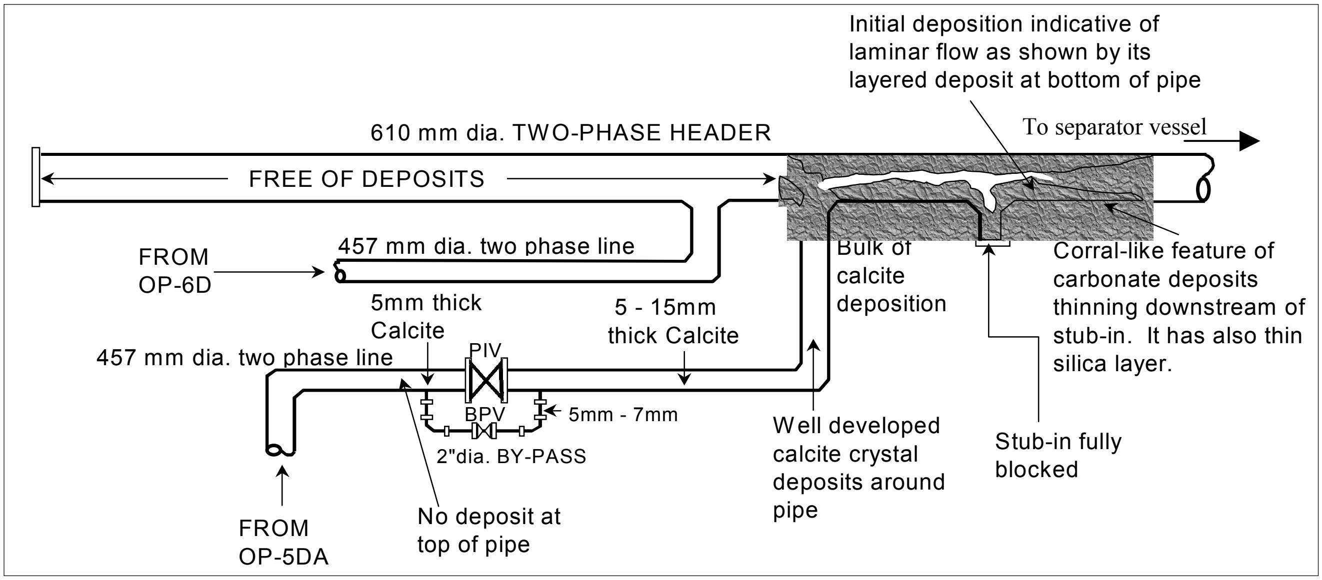

Fig.5 Well OP-5DA/OP-6D pipe inspection results.

Table 1 OP-5DA/OP-6D HEAT & MASS BALANCE SIMULATION

WELLS	DATE	P (bara)	T (deg.C)	MF (kg/s)	H (kJ/kg)	FLOW REGIME	WF	SF	Additional Flash	WF decline	Ca TD (ppm)
OP-5DA (BL)	02/05/98	7.85	170	14.30	2417	Wave	17%	83%			18
OP-6D (BL)	02/19/98	7.84	186	20.50	2780	Turbulent	0.15%	99.85%			0
MIX (H)		7.84	170	34.80	2630	Wave	7%	93%	12%	41%	260
OP-5DA (BL)	06/30/98	7.72	169	12.00	2600	Wave	8%	92%			0.39-0.92
OP-6D (BL)	06/30/98	7.71	169	19.50	2641	Wave	6.20%	93.82%			0
MIX (H)		7.71	169	31.00	2625	Wave	7%	93%	1.1%	12.5%	6-13
OP-5DA (BL)	12/23/98	7.87	170	14.80	2696	Wave	4%	96%			17
OP-6D (BL)	01/14/99	7.86	186	18.30	2780	Turbulent	0.15%	99.85%			0
MIX (H)		7.86	170	33.00	2743	Wave	1%	99%	3%	75%	1670-1710

P - Pressure T - Temperature H - Enthalpy BL - Branch Line TD - Total Discharge
MF - Mass Flow SF - Steam Fraction WF - Water Fraction H - Header

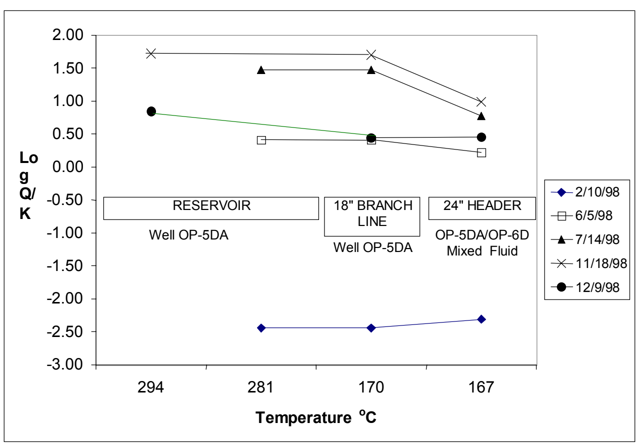

Fig.6 Calcite saturation index simulation results.