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Calcite Scale Inhibition: The Case of Mahanagdong Wells in Leyte Geothermal Production Field, Philippines

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ABSTRACT

The formation of a calcite scale blockage inside the wellbore of a production well has been one of the problems encountered in Mahanagdong. The presence of a calcite blockage was confirmed in at least six (6) wells, which is mainly attributed to high calcite saturation indices in their fluids. These blockages constrict the flow of geothermal fluids in these wells thus significantly reducing their output. Based on production historical data, decline in field steam availability in Mahanagdong-A sector is mainly attributed to this problem.

To meet the steam requirement of the MG-A power plant, output of the wells with calcite blockage should be recovered. Thus, mechanical clearing using a drilling rig was conducted in each of the affected wells to remove the blockage. However, due to cost and risk involved in conducting periodic mechanical clearing, the use of a chemical inhibitor in preventing recurrence of calcite blockage deposition inside the wellbore was considered.

To date, a calcite inhibition system was already installed in two (2) of the affected wells in Mahanagdong. The calcite inhibition system basically consists of surface injection facility for the preparation and injection of chemical solution and a downhole injection facility to allow injection of chemical solution inside the wellbore of a producing well below the flash point depth.

Based on initial results, decline rate in both wells with installed calcite inhibition system has been reduced significantly from an average of 4.0 kg/s-month to less than 0.5 kg/s-month in terms of total massflow.

1. INTRODUCTION

The Mahanagdong geothermal field (Fig. 1), located in the island of Leyte, is part of the Leyte Geothermal Production Field (LGPF), which has been explored and operated by the Philippine National Oil Company-Energy Development Corp. (PNOC-EDC) since the late 1970's. At present, there are the two (2) main and two (2) optimization power plants installed in the area with a combined generating capacity of 200 MWe. The steam requirements of these power plants are being supplied by 20 production wells from MG-A and MG-B sectors of the Mahanagdong field (Fig. 2).

When Mahanagdong field started production in 1997, MG-A sector enjoyed an ample steam supply for the requirement of its power plants. However, in just two years, in-situ steam supply begun to drop, which was mainly attributed to the progressive decline in output of wells in the southern part of the Mahanagdong field due to calcite blockage.

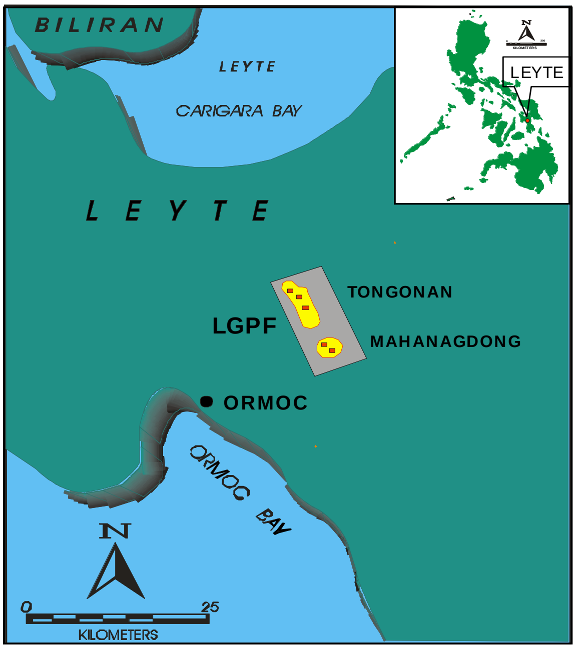


Figure 1: Location map of the Leyte Geothermal Production Field (LGPF) showing the Tongonan and Mahanagdong Geothermal Fields.

Previous works by Martinez (1997) showed that fluids in these wells are saturated with respect to calcite at reservoir condition. Upon boiling to a lower flash point temperature (~240-260°C) inside the wellbore, these fluids became supersaturated with respect to calcite (CSI>1.0) thus increasing the potential for calcite blockage formation.

Boiling leads to a strong reduction in CO_2 partial pressure due to transfer of CO_2 in the steam phase. Degassing of CO_2 increases pH and strongly increases carbonate ion concentration. It is mostly these increases that are responsible for making initially saturated geothermal water supersaturated with calcite (Arnorrson, 1989). Bicarbonates participate in formation of calcite scales at the flashpoint according to the following chemical reaction:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_{3,s} + CO_2\uparrow + H_2O.$$

So in effect, the increase in HCO_3 also enhances the rate of forward reaction or the formation of calcite scales ($CaCO_3$).

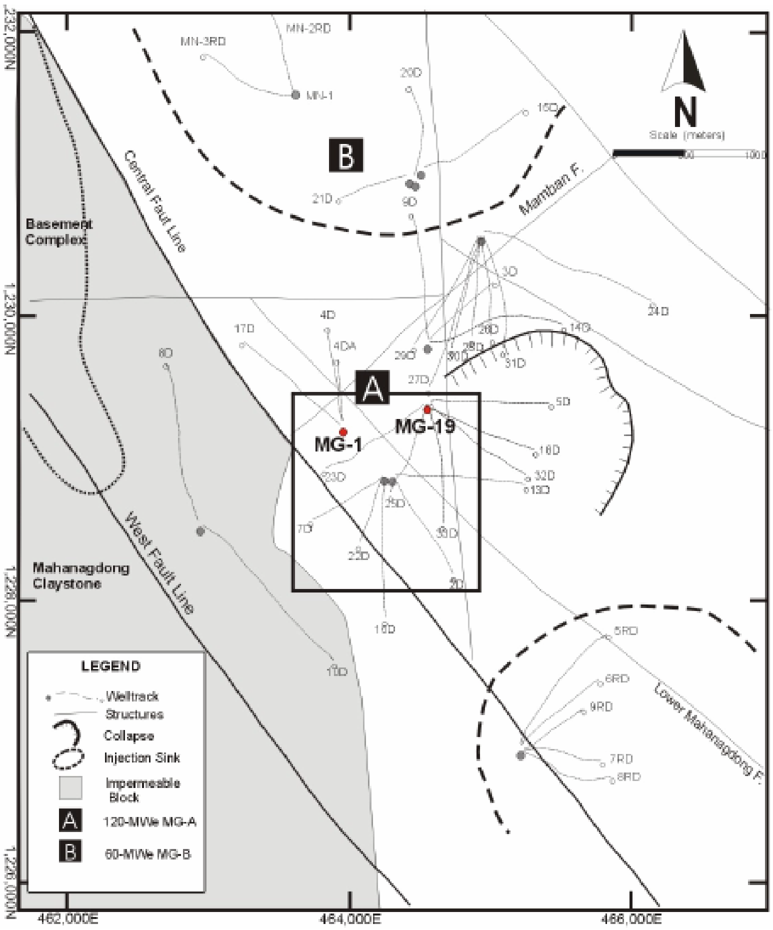


Figure 2: Map of the Mahanagdong Geothermal Field indicating the production wells in the SW section of the field (within the unshaded square) with calcite saturated fluids.

Summarize in Table 1 are the wells in Mahanagdong-A sector which showed significant output decline in year 2000 due mainly to calcite blockage. A total of six (6) wells out of the 12-wells compliment for MG-A sector are affected by calcite blockage deposition (Fig. 2). This accounted to ~58 kg/s loss in steam supply to the power plants, which is equivalent to ~26 MWe at steam rate of 2.258 kg/s/MWe.

Table 1. List of Mahanagdong wells with calcite blockage and change in well output between the periods 1997 to 2000.

Well Name	ΔMassflow in kg/s	ΔSteamflow in kg/s	ΔOutput in MWe
MG1	19	4.4	2.0
MG2D	42	8.1	3.5
MG7D	39	7.6	3.4
MG19	19	6.3	2.9
MG22D	37	8.0	3.5
MG23D	99	23.1	10.2
TotalΔ	255	57.5	25.5

The main objective of this paper is to present the calcite scale inhibition conducted in wells MG-1 and MG-19, as a means to maintain well output and sustain production in the Mahanagdong field.

2. CHEMICAL INHIBITION

Past method of removing the calcite blockage to recover well output is through mechanical clearing using a drilling rig. Although this method may be effective in removing calcite blockages, this will not totally prevent calcite deposition thus revenue losses are encountered. In addition to that is the cost and risk involved in conducting periodic well workover.

Chemical inhibition, on the other hand, has gained importance both technically and economically in preventing calcite deposition inside the wellbore. The mechanisms involved in this method are: a) prevent precipitated scale crystals from adhering to surfaces; and b) absorption onto the surface of incipient crystals and thereby distorting the crystal structure so that the crystal is prevented from growing. The choice of a suitable inhibitor and the system for injecting it into the well is critical in this case (Argueta, 1995).

2.1 Surface and Downhole Injection Facilities

Figure 3 shows the schematic diagram of the calcite inhibition system installed in Mahanagdong wells. The surface injection facility basically consists of: a) large capacity tanks connected to a centrifugal pump for preparation and storage of solution; and b) dosing pump for injection of solution into the well through the capillary tubing.

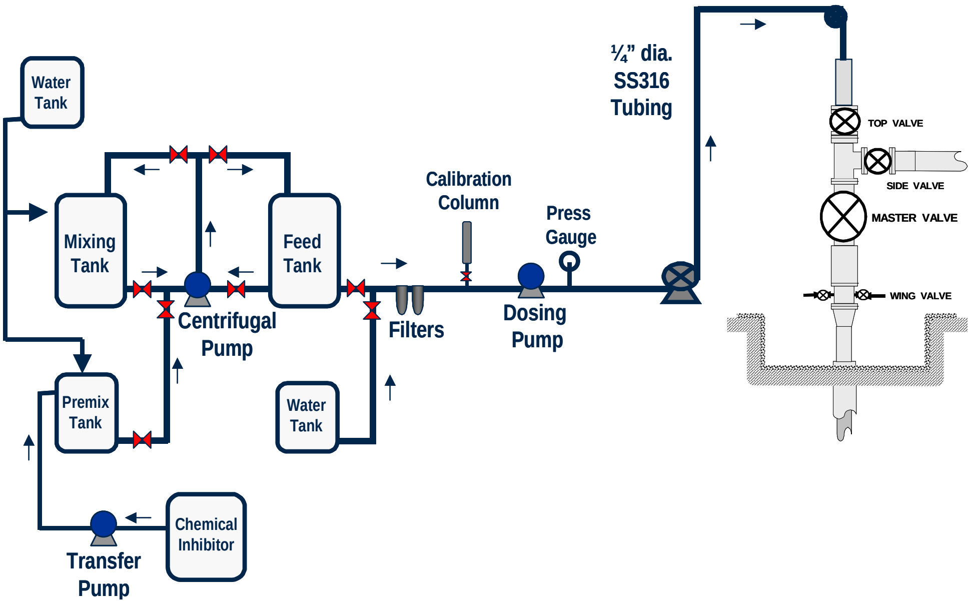


Figure 3. Schematic diagram of the surface injection facility for the calcite inhibition system (CIS).

The downhole injection facility is composed of 2000 m length of a 6.35 mm (0.25 in) SS-316 capillary tubing. The tubing is held at the desired injection depth by weighted sinker bar with an injection head and nozzle assembly. The sinker bar weight is calculated to withstand the force of the rising fluid but still within the safe mechanical load limit of the capillary tubing. The tubing is held in place at the surface by a pack-off assembly designed to seal off well pressures while allowing the tubing to hang inside the well (Fig. 4). A hang-down string (3 in. drill pipe) with a square Teflon pack-off at the bottom is used to protect the capillary tubing near the wellhead.

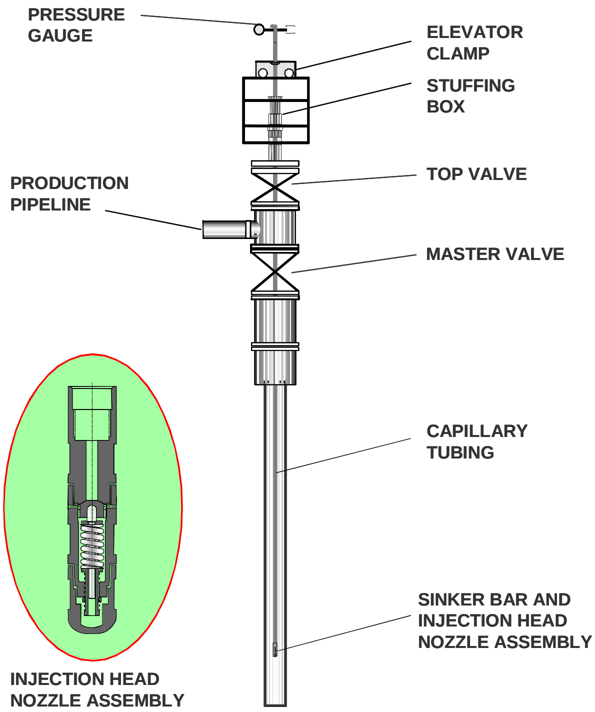


Figure 4. Schematic diagram of the downhole injection facility for the calcite inhibition system (CIS).

2.2 Chemical Inhibitors

The most common types of inhibitors currently in use today for calcite scale control include the polyacrylic acid (PAA) and polymaleic anhydrides (PMA). Both types of inhibitors are acidic in nature and have the carboxylic acid (COOH) functional group (Ramos-Candelaria, 1999). The PAA's have a straight chain with one COOH in the monomer, while the PMA's have a ring for the monomer with 2 COOH groups (Fig. 5).

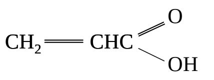
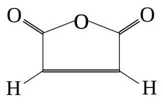
Acrylic Acid	Maleic Anhydride
	

Figure 5. Chemical structures of common base units

As mentioned above, the polymer of these inhibitors develops negative charges in water, attaches itself to the growing $CaCO_3$ micro-crystals causing distortion and interferes with the ability of the crystal to keep growing in a precise geometric pattern. In addition, a large negative charge is imparted on the aborted micro-crystals causing it to repel other like particles. The net effect is that a very small non-adherent crystals are formed which can be easily swept away by fluid flows. The inhibitors that have been used in production fields of PNOC-EDC to control calcite scaling in production wells are shown in Table 2.

Table 2. List of calcite inhibitors used in production fields of PNOC-EDC

Inhibitor	Type	Effective Line Conc for Inhibition (ppm)
N9354	Polyacrylates	5 ppm
DG9349	Polymaleic Anhydride	2 ppm

The N9354 inhibitor has been used successfully in MGPF wells SP-4D and APO-1D since year 1999 and 2000, respectively (Ramos-Candelaria, 2000). The same inhibitor was used initially in well MG-1 in Mahanagdong in year Apr 2001. However, decision to shift to another inhibitor DG9349 in Sept 2001 aside from the chemical cost, was based mainly on the plugging of the capillary tubing in well MG-19 after only 5 days of operation and the observed continuous decline in MG-1 massflows even with calcite inhibition.

In both Mahanagdong wells, the flash point depth was determined at a much deeper depth of 1650 to 1750 mMD thus injection depth of the inhibitor was set at least 100 m below the flash point. At this depth, fluid temperature based on geothermometers and KT/KP survey in these wells ranged from 265 to 280°C. In contrast, injection point temperature of the MGPF wells SP-4D and APO-1D is close to 240°C only, which raised concerns on the effectiveness of the N9354 inhibitor at higher temperature condition.

Subsequent field and laboratory trials have shown that N9354 can only be effective at injection temperature ≤ 250°C, as in the case of wells SP-4D and APO-1D in MGPF (Ramos-Candelaria, 2001). In the case of wells MG-1 and MG-19 with fluid temperatures of 265°C and 280°C, respectively, it is believed that N9354 is susceptible to thermal degradation (indicated by formation of black deposits) resulting to loss of its inhibition property. The choice therefore of a suitable inhibitor should take into consideration the thermal stability of the inhibitor under expected downhole pressure and temperature of the well.

2.3 Field Application

To date, of the six (6) wells in Mahanagdong identified to have encountered calcite blockage, Calcite Inhibition Systems (CIS) were installed only in wells MG1 and MG19 in April and September 2001, respectively. Prior to the commissioning of the CIS, wells MG-1 and MG-19 were worked-over to remove the blockages tagged during run of 3” and 6” go-devil tools. Figure 6 shows the location of the blockages tagged inside the wellbore of these wells. In both wells, the deposition zone is located near the top of the liner down to the inferred flash point depth inside the well. After the work-over, go-devil surveys were conducted to ensure that the wells are cleared down to its total depth. Then followed by a flowing pressure and temperature survey (PATS) at various wellhead pressures together with the bore output measurement (BOM).

Data that are obtained from the PATS are used to estimate the flash point depth using the HOLA or WELLSIM programs. The location of the flash point depth inside the wellbore should be known prior to capillary tubing run-in as this will be the basis for the setting of the injection depth. For wells MG-1 and MG-19, the flash point depths were determined at 1650 mMD and 1750 mMD, respectively. Injection of the inhibitor in both wells was set at 100 m below the flash point depth.

The expected pump injection pressure can be estimated also from the PATS data. This is important in the specification of the dosing pump injection rate and operating pressure. In the case of the installed system in MG-1 and MG-19, the dosing pumps used in the inhibition have a maximum design pressure of 900-1500 psi with the dosing rate of 26-50 LPH. Moreover, the concentration and dosing rate of the inhibitor solution is dependent on the total massflow of the well and the required line concentration provided by the supplier to ensure effective inhibition. The concentration of the inhibitor solution, however, should not be too high (≤ 10% v/v) as problems related to viscosity and pump operation will be encountered.

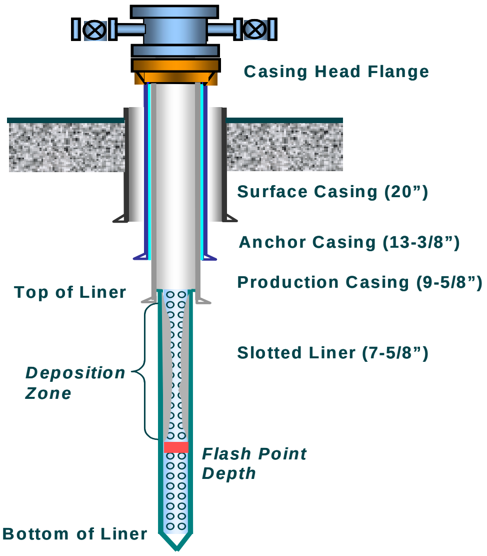


Figure 6. Typical calcite deposition zone in wells MG-1 and MG-19 (not to scale).

The current method of determining the actual inhibitor concentration in the feed solution and two-phase discharge line is based only on the Hyamine method. The Hyamine method is a test for the polymer of the inhibitor, which forms an emulsion or turbidity when it comes out of solution at neutral pH. However, this method provides only a semi-quantitative analysis of the inhibitor concentration and is not accurate in determining the actual inhibitor concentration in the two-phase discharge line. The control of inhibitor dosing rate is still based on theoretical mass balance calculation dependent on the massflow of the well. Spot determination of inhibitor concentration in the well discharge is still under development.

Table 3 and 4 summarizes the pump operation data and concentration of inhibitors used relative to the well total massflow. The annual consumption of chemical inhibitor varies depending on the massflows of the wells, effective line concentration for inhibition as provided by the supplier and the dosing rate.

Table 3. Pump data and N9354 concentration relative to MG-1 and MG-19 mass flows.

Well	N9354				
	Req’d Line Conc (ppm)	Inj Sol’n Conc (%v/v)	Dosing Rate (LPH)	Inj Press (psi)	TMF (kg/s)
MG-1	5	10%	11	155-530	80
MG19	5	10%	13	200-580	90

Table 4. Pump data and DG9439 concentration relative to MG-1 and MG-19 mass flows.

Well	DG9349				
	Req'd Line Conc (ppm)	Inj Sol'n Conc (%v/v)	Dosing Rate (LPH)	Inj Press (psi)	TMF (kg/s)
MG-1	2	3	10	210-280	60
MG19	2	5	10	20-480	85

3. DISCUSSION OF RESULTS

3.1 Well MG-1

The calcite inhibition system (CIS) at MG-1 was first commissioned in April 2001 after its third work-over. The injection depth was set at 1750 mMD, which is 100 m below the flash point depth of the well. Initially, a 10% N9354 solution was used as the inhibitor with dosing rate of 11 LPH. However, after almost a year, it was observed that MG-1 massflow showed continuous decline even with inhibition (Fig. 7). The calculated decline rate during this period is 1.56 kg/s-month.

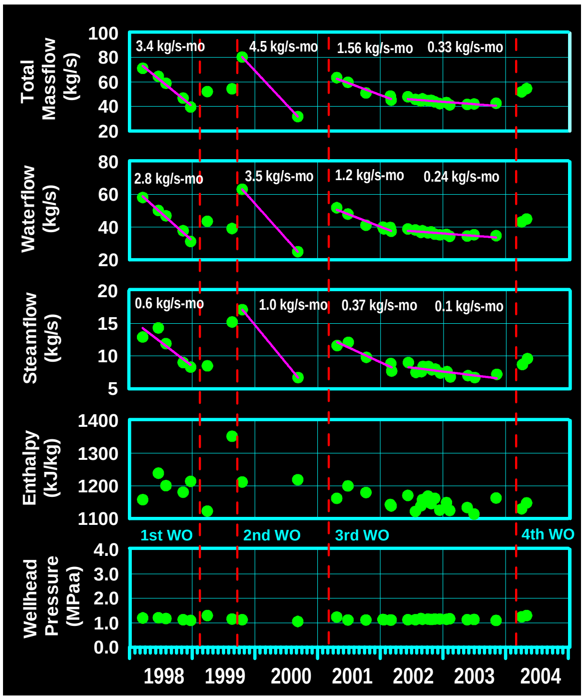


Figure 7. Well MG-1 massflow trends with time (in kg/s) showing the calculated decline rates per month in total massflow, steamflow and waterflow.

In April 2002, it was decided to shift to DG9349 inhibitor, which was already used in MG-19 with acceptable results at high temperature application. Since MG-1 has relatively lower massflow of ~50 kg/s at that time, a 3% DG9349 feed solution was used at a dosing rate of 10 LPH. From May 2002 to August 2003, monitoring of massflow indicated relatively lower decline rate of 0.33 kg/s-month.

In August 11, 2003, inhibition was temporarily stopped due to blockage at the injection nozzle and sections of the capillary tubing, which upon analysis, showed degraded components of DG9349 inhibitor. The cause of the tubing blockage was traced to the emergency throttling of MG-1 block valve at the branchline to prevent overflow of effluents from the thermal pond during the MG-A plant PMS. At this condition, degradation of the chemical inhibitor DG9349 occurred as a result of the prolong exposure to high temperature MG-1 fluids (~255-260°C) at constricted flow condition. The wellhead pressure (WHP) of MG-1 increases from its normal operating pressure of 1.2 MPag to 2.8 MPag during this period.

The well was worked-over in January 2004 with a slight improvement in its output. The CIS was re-commissioned only in April 2004 after the new capillary tubing arrived. The current dosing rate is at 10 LPH using a 3% DG9349 feed solution. The measured massflow as of May 2004 is 55 kg/s, which still showed increasing trend since the last work-over.

3.2 Well MG-19

The calcite inhibition system (CIS) at well MG-19 was first commissioned in September 8, 2001 after its third work-over to remove the calcite blockage. A10% N9354 feed solution was used as the inhibitor with injection depth set at 1850 mMD (~283°C zone temperature) and dosing rate of 13 LPH. However, after only 5 days of operation, the capillary tubing was pulled-out to remove the blockage (very hard metallic black adherent deposit) developed inside the injection nozzle believed to be compounds of N9354 inhibitor.

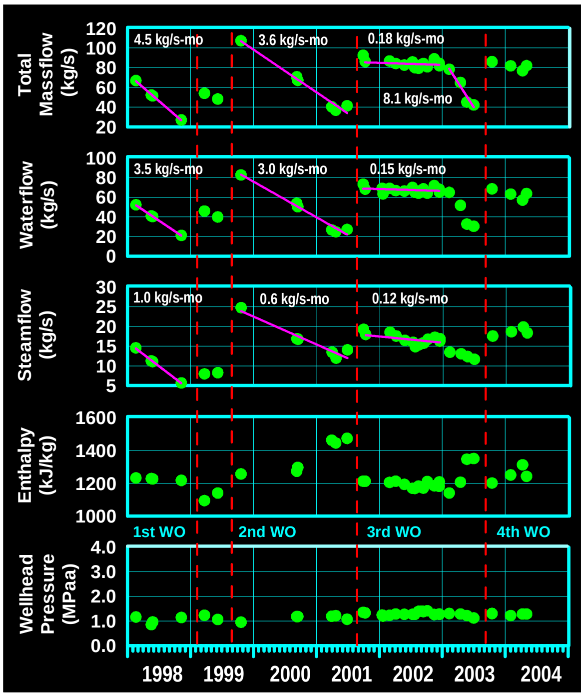


Figure 8. Well MG-19 massflow trends with time (in kg/s) showing the calculated decline rates per month in total massflow, steamflow and waterflow.

After evaluating other types of inhibitor suitable for high temperature application, MG-19 CIS was re-commissioned on October 2001 at same injection depth of 1850 mMD. This time, a 5% DG9349 chemical inhibitor solution was used with the dosing rate set 10 LPH. Well output monitoring between the period October 2001- September 2002 indicate lower decline rate in the massflow of 0.18 kg/s-month (Fig. 8). Previous decline rates prior to inhibition ranged from 3.6 to 4.5 kg/s-month between the period 1998-1st half 2001.

In September 2002, the top valve of MG-19 was accidentally shut during diversion to the silencer in preparation for the scheduled plant PMS. This caused the capillary tubing to break resulting to fishing operation of the ~1800 m tubing plus sinker bar left inside the wellbore. After procuring new capillary tubing, MG-19 CIS was again re-commissioned on December 2002 at same dosing rate of 10 LPH of 5% DG9349 solution. However, the injection nozzle was set at 1450 mMD only after encountering obstruction during run-in. The programmed injection depth of MG-19 is at 1850 mMD, 100 m above its flash point depth of 1750 mMD. The succeeding output measurements showed significant output decline, which indicate that at this condition, inhibition was not effective in preventing further deposition of calcite in MG-19. The estimated massflow decline rate during this 5-month period was at 8.1 kg/s-month.

The capillary tubing was pulled-out in July 2003 and well MG-19 underwent mechanical clearing in August 2003. The MG-19 CIS was re-commissioned in September 2003 at injection depth of 1850 mMD with dosing rate of 10 LPH 5% DG9349 feed solution. Currently, MG-19 has shown a stable massflow of ~80kg/and steamflow of ~20 kg/smonth since the last workover.

4. CONCLUSIONS

Chemical inhibition has gained importance both technically and economically in preventing calcite deposition inside the wellbore. Aside from eliminating the down time of production wells with calcite blockages, it also reduces the risk and cost involved in conducting periodic workover.

The success of chemical inhibition hinges mainly on the thermal stability of the inhibitor. The choice of suitable inhibitor should not be based only on the cost but as well as on its effectiveness at the expected subsurface temperature and pressure of the reservoir. Field and laboratory test could be conducted to check the inhibition property and thermal stability of the inhibitor prior to long term application.

Determination of the well flash point depth from PATS data is also important since theoretically, if the reservoir fluids is already saturated with respect to calcite, it is at this point where deposition of calcite blockage will likely occur due to flashing. Moreover, the injection of inhibitor is normally set below the flash point depth.

The injection of inhibitor solution should be continuous to ensure that the required effective concentration of the inhibitor at the well discharge fluids is maintained. Thus, the pump use in delivering the inhibitor through the capillary tubing should have flowrate capacity and operating pressure well above the required dosing rate and injection pressure.

In the case of the Mahanagdong wells, although besiege by several problems since at the start of operation, chemical inhibition is generally successful in reducing the decline rate in their massflows. Based on the results, the decline rate in both wells with installed calcite inhibition system has been reduced significantly from an average of 4.0 kg/s-month to less than 0.5 kg/s-month in terms of total massflow.

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