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Mitigation of Two-Phase Header Scaling in an Acidic System

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ABSTRACT

Mineral scaling is a common problem in geothermal power facilities. This scale deposition is usually caused by changes in the geothermal fluid temperature or composition and chemistry. Precipitation of minerals can limit fluid flow within the steam field equipment, reducing plant efficiency and increasing maintenance costs.

Layers of scales are commonly found in most parts of the geothermal steam gathering system. However, substantial amounts of deposited mineral scales are usually observed in the pipelines and vessels that handle brine supersaturated with respect to silica.

This paper focuses on a less common scaling location, the geothermal two-phase pipelines. In this case, iron sulfide and silica deposition is observed in a two-phase pipeline shared by several wells for transport to the downstream facility. The scaling is caused by the mixing of acidic, high-silica fluids with neutral pH fluids, of different enthalpies.

Header blockage can compromise operational safety by increasing pipeline pressures, cause a decrease in well production from increasing wellhead pressures, and also increase costs due to frequent pipe cleaning. Online chemical inhibitor dosing was introduced to the system, for eighteen months, to slow the scale deposition, keep pipeline pressure from increasing and lengthen the time between pipe cleaning. Continuous dosing has kept the pressure constant since commissioning but not enough to totally prevent scale deposition which was still observed upon inspection. Further studies will include optimization of the chemical inhibitor dosing.

1. INTRODUCTION

Pad A is located in the Mahanagdong-B sector of the Leyte Geothermal Field in the Philippines (Figure 1). The pad is located ~2 km from the separation station. It currently has four production wells contributing to the system through a common 42 in (1.06 m) diameter two-phase line (Figure 2).

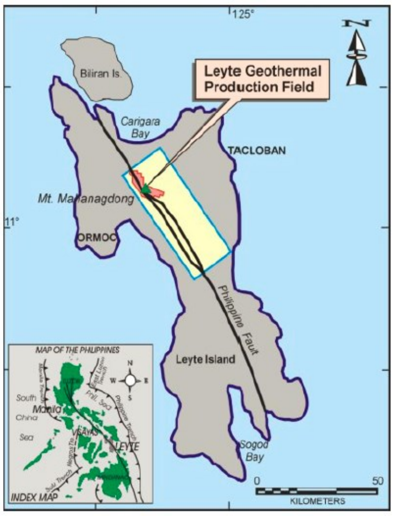
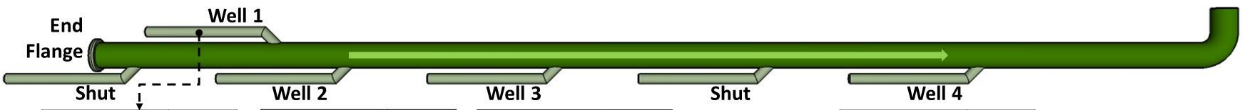


Figure 1: Location of Leyte Geothermal Production Field in the Philippines (Meneses, 2015).



H, kJ/kg	2309
TMF, kg/s	39.6
WF, kg/s	9.50
pH	6.5
SiO_2, ppm	787
SSI (@ 190°C)	0.92
Fe, ppm	0.25
H_2S, ppm	**11.2**

H, kJ/kg	2213
TMF, kg/s	8.33
WF, kg/s	2.39
pH	**3.4**
SiO_2, ppm	639
SSI (@ 190°C)	0.74
Fe, ppm	**9.71**
H_2S, ppm	1.88

H, kJ/kg	1645
TMF, kg/s	51.7
WF, kg/s	29.7
pH	**3.7**
SiO_2, ppm	**1068**
SSI (@ 190°C)	**1.24**
Fe, ppm	**9.77**
H_2S, ppm	1.68

H, kJ/kg	2481
TMF, kg/s	40.1
WF, kg/s	6.13
pH	**3.9**
SiO_2, ppm	737
SSI (@ 190°C)	0.86
Fe, ppm	**9.61**
H_2S, ppm	0.24

Figure 2: Pad A two-phase header with physical and chemical characteristics of online wells (as of July 2018); where H is enthalpy, TMF is total mass flow, and WF is water flow.

Scaling within the Pad A two-phase line was first documented in October 2011. Historical scale deposition in the common two-phase line was attributed to the mixing of incompatible fluids of the Pad A wells (Jamero, et al., 2018). Most of the wells in Pad A are unsaturated with respect to silica, so mixing them within the two-phase header should have minimal risk of silica deposition. However, Well 3 is highly supersaturated with silica, with an SSI of 1.24, at line condition of 190°C. Yet, despite the high SSI level, scales are not documented in the Well 3 branch line because its low-pH retards silica polymerization and mitigates silica deposition (Alcober, et al., 2005).

1.1 Shutdown of the Common Two-phase Line on May 2017

Pipeline cleaning was scheduled every 2 years considering the historical scaling episodes. However, on February 2017, cut-in and utilization of all four wells led to an increase in common line pressure of 0.75 MPag in 3 months (Figure 3). The scale blockages led to the increase in the wellhead pressures of the wells thus effectively throttling their discharges and incurring 4 MW production loss. Shutdown was prompted at the end of May 2017 before the common two-phase line pressure limit was breached.

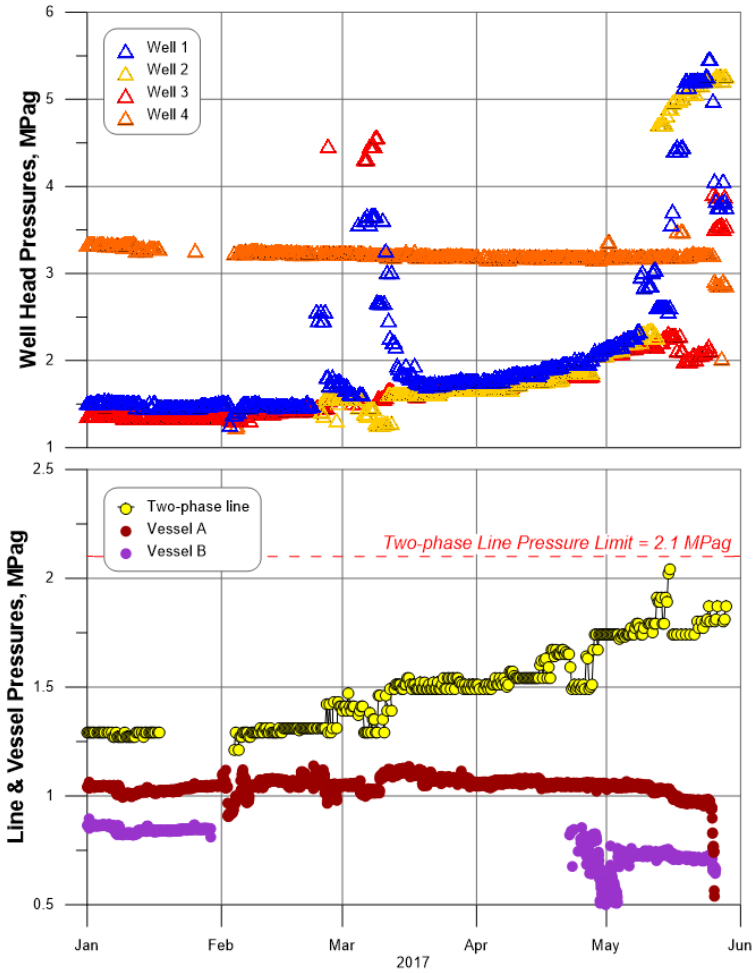


Figure 3: Pad A well head, two-phase line and separator vessel pressure trending from January to June 2017.

1.2 Root Cause Analysis

Inspection of the common two-phase line in June 2017 showed major scaling right after the stub-in of Well 1 up to a few meters after the stub-in of Well 4 (Figure 4). Massive scaling, with minimal to no clearance, was observed downstream of the Well 3 stub-in. This constriction may have forced the acidic, high silica fluids to backflow to the upstream section and mix with the neutral fluids of Well 1. This explains the presence of massive scales right after the Well 1 stub-in. Further inspection shows the scale deposition decreasing as the mixed header fluid flows further downstream, from the Well 4 stub-in.

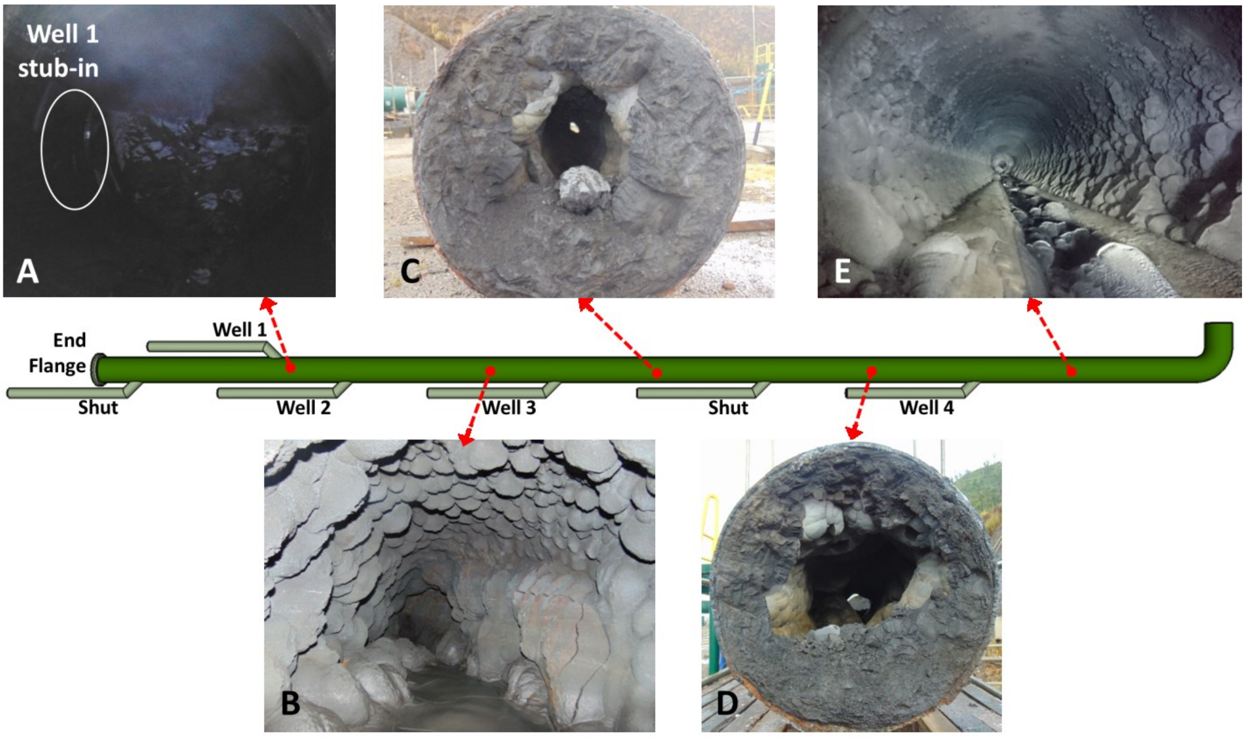


Figure 4: Scaling in Pad A common two-phase line documented on June 2017. Well 1 is neutral while Wells 3 and 4 have acidic discharges.

Scale samples from the common two-phase line were collected for petrologic analysis. Results, analyzed by Concepcion and Rosell (2017), show that the scale samples are composed of multi-layered corrosion products with thin basal layers and/or inter-layers of amorphous silica. Some include interstitial/disseminated anhydrite deposits and transported impurities. Percent composition of the scales, as shown in Table 1, reveal that majority of the deposition are made up of metal sulfides, iron oxides and amorphous silica.

Table 1: Summary of petrologic results for Pad A scale samples from Figure 4.

Location (Figure 4)	Petrologic Analysis		
	Corrosion Products	Amorphous Silica	Anhydrite
A	~95% (pyrrhotite, sphalerite, minor hematite/goethite)	~5% (very thin basal layers of sulphides)	
B	~90% (pyrrhotite, sphalerite)	~10% (very thin basal layers of sulphides)	<1% (interstitial)
C	~60% (pyrrhotite, minor galena, chalcopyrite, pyrite)	~40% (thin discontinuous inter-layers with corrosion products)	
D	~50% (pyrrhotite, hematite/goethite)	~30% (thin discontinuous inter-layers with corrosion products)	~20% (disseminations within corrosion products)
E	~70% (pyrrhotite, hematite/goethite)	~30% (thin discontinuous inter-layers with corrosion products)	<1% (disseminations within corrosion products)

Physical separation of the incompatible fluids was considered. However, the 1.8 km distance of Pad A from the separator station would not make a second common two-phase line financially advisable. A shorter second common two-phase line was proposed for construction that would be the same length as the more scale prone areas. The redundant line would extend for 200 m and enable continuous operation and contribution of the wells in Pad A whenever the scale depositions would constrict the original pipeline.

While the 200 m redundant common two-phase line was being explored and pursued, online chemical dosing was elected to mitigate the scale deposition in the existing common two-phase line.

2. Online Inhibitor Injection

The Pad A wells are composed of two types of fluids: the acidic fluids from Wells 2, 3, and 4; and the neutral pH fluids from Well 1. The scaling issue lies with the characteristics of Well 3. Well 3 is highly supersaturated with silica, as shown in Figure 2, but precipitation is prevented by its acidic nature. However, addition of Well 1 to the three acidic wells increases the pH of the resultant solution to around 5.5 which allows the excess silica to deposit. The high water flow of Well 3 provides the massive amount of silica deposition in the pipeline. The high percentage metal sulfides and iron oxides in the scale samples can be attributed to the high hydrogen sulfide content of Well 1 and the high iron content of Wells 2, 3, and 4. These form the basal and inter-layers of corrosion products on which the silica attaches to.

A silica inhibitor (C1) and a metal sulfide inhibitor (C2) were chosen for the online two-phase line chemical dosing. The silica inhibitor was previously tested on a side stream set-up using separated brine from the same Mahanagdong-B system and yielded an 80% reduction in silica scaling (Jamero, et al., 2013). The silica-sulfide inhibitor combination was first tested in a different two-phase line with the same silica and metal sulfide deposition, in different percent compositions (Jamero, 2018).

The dosing strategy for the Pad A common two-phase line would be to inject at two points: (1) inject 12 ppm C1 into the branch line of the high silica Well 3, and (2) inject 7 ppm C2 into the branch line of high hydrogen sulfide Well 1. Additional 3 ppm C2 will also be injected into the Well 3 branch line to compensate for its high iron content.

Online scale mitigation system (SMS) dosing for Well 1 and 3 branch lines were commissioned on June and August 2017, respectively. The almost two month delay in commissioning was caused by the 6.5 magnitude earthquake that hit Leyte, Philippines last July 2017, which led to some interruptions to the schedule. Continuous online SMS injection was conducted for 14 months with only one change in the dosing strategy after 11 months. Cut out of Well 3 from the system due to a scheduled work over led to the transfer of the 12 ppm C1 dosing from the Well 3 branch line to the Well 1 branch line. There was also no need to add the additional 3 ppm C2 to the SMS since Well 3 was out. The system was decommissioned on November 2018 due to the scheduled Pad A common two-phase line shutdown for the 200 m redundant two-phase line stub-in installation.

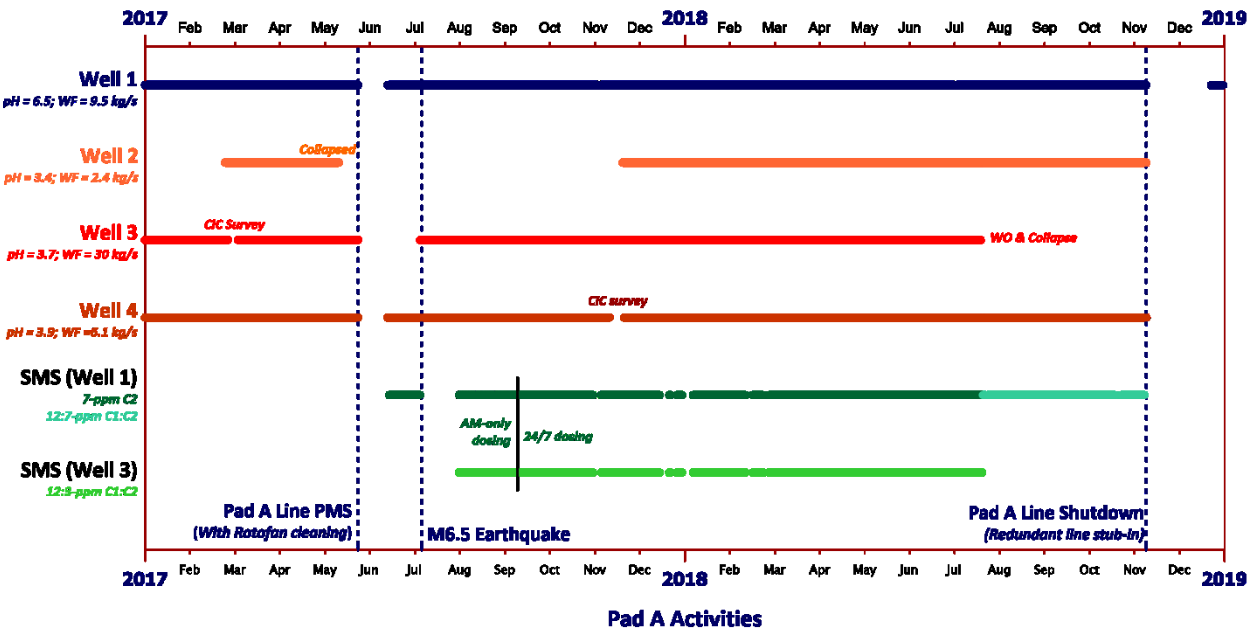


Figure 5: Timeline of Pad A well activities during the online scaling mitigation system (SMS) dosing.

2.1 Results and Discussion

Stable high pressure operation was reached in October 2017, with three wells online, with the fourth well cut-in on November 2017. Continuous monitoring of the Pad A common two-phase line and wellhead pressures was conducted simultaneously with the online SMS to determine if the scale deposition has constricted the line, as observed in March to May 2017 before the shutdown.

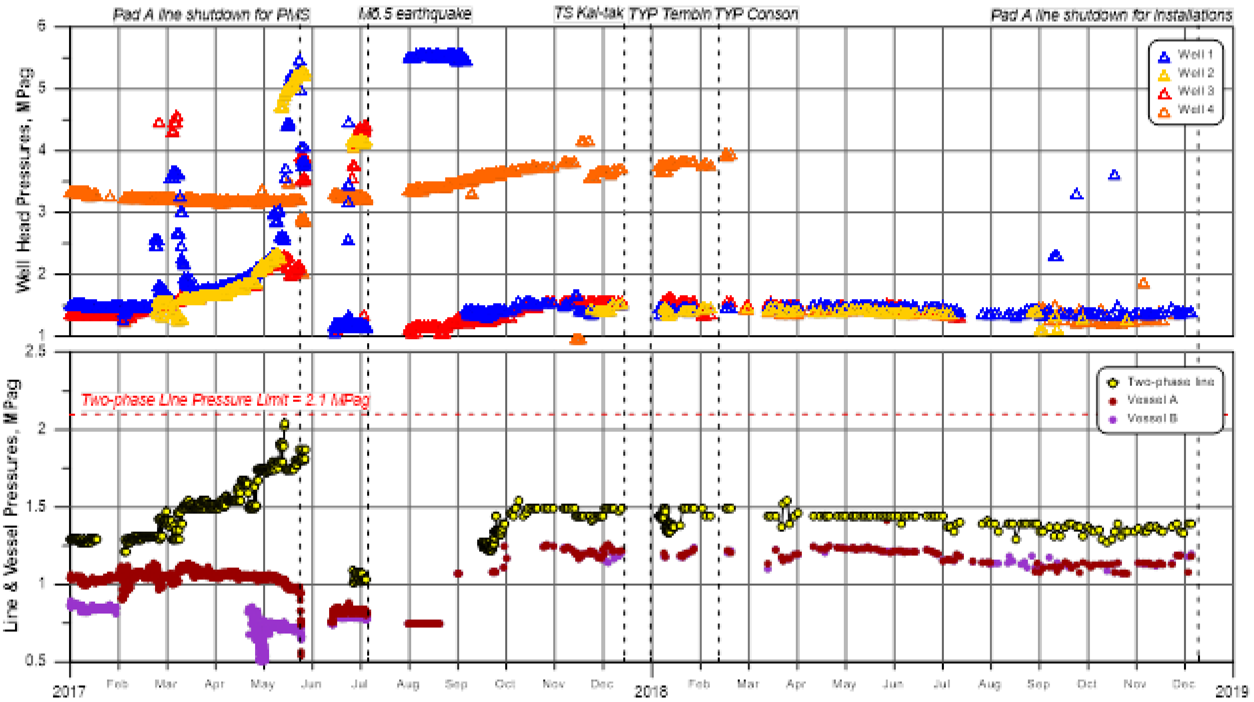


Figure 6: Pressure monitoring for Pad A well head, two-phase line and separator vessels during the online SMS.

Pressure data (Figure 6) show that there is no change in the common two-phase line pressure that is not in tandem with the separator vessel pressures. Wellhead pressures also show no gradual increase that may indicate throttling of the wells due to growing scale deposition.

Chemistry of the wells and in the common two-phase line was also monitored. Sampling locations are shown in Figure 7. Each two-phase line sampling point represents the fluid mixture after each well is introduced into the common line system.

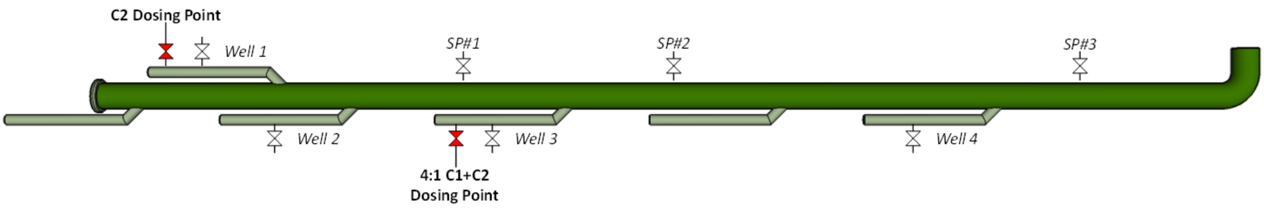


Figure 7: Pad A common two-phase line sampling locations.

As evaluated, the addition of Well 1 fluids into the common two-phase line increases the pH of the acidic fluids by 2 units. This promotes the deposition of silica from Well 3, which is greater than 1000 ppm at a 1.2 SSI. The drop in silica and SSI, as shown in Figure 8, indicates some silica precipitation which was not completely eliminated by the chemical inhibitor dosing. This may be validated once the line is cut-out for inspection and maintenance.

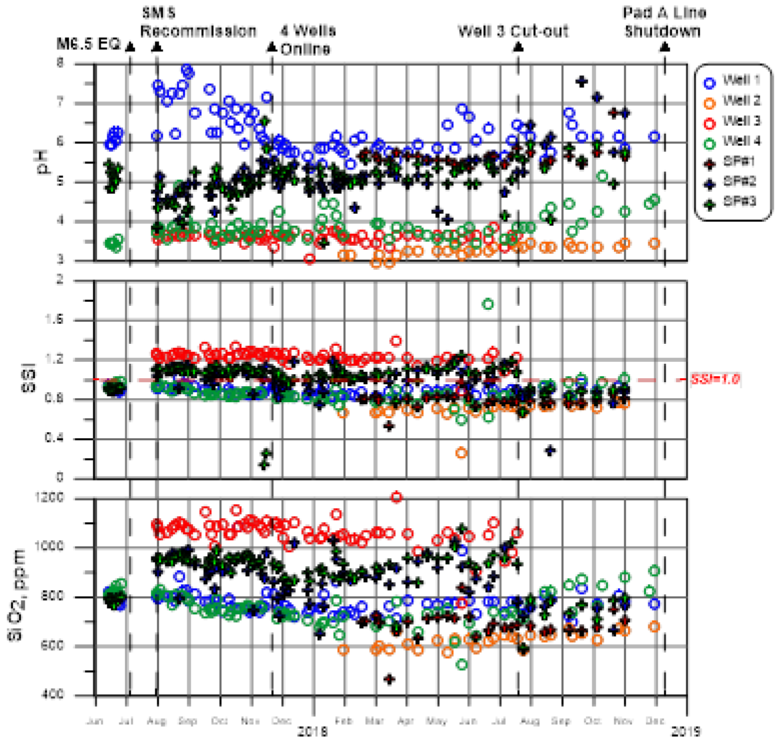


Figure 8: Chemistry monitoring of the Pad A wells and two-phase line during the online SMS.

After the cut-out of Well 3, there is a noticeable decline in silica in the common two-phase line but the pH increased to 6.0. This is still a cause for concern, since the remaining Wells 2 and 4 have high iron content which can still accelerate the precipitation of silica in the mixed solution (Brown, 2013). This will be addressed by increasing the dosing rate of the silica inhibitor whenever Well 3 is cut-out from the system.

3. CONCLUSION AND RECOMMENDATIONS

Using the pressure limit of the common two-phase line and the pressure observations documented prior to the May 2017 shutdown, the online SMS injection is effectively keeping the line pressure from increasing due to scale deposition. Chemistry monitoring also shows that the silica deposition is slowed down by the continuous inhibitor dosing in the system. Common two-phase line SSI remains to be greater than 1.0, which indicates that only part of the excess silica is deposited in the pipeline with the other part kept in solution.

Table 2: SMS monitoring data compared to established parameter criteria as of December 2018.

Data	Parameters	Criteria	4 Wells Online	3 Wells Online
Pressure	Two-phase line pressure	<2.1 MPag (Two-phase line pressure limit)	1.45 MPag (29 Jun 2018)	1.40 Mpag (5 Dec 2018)
	Two-phase line pressure increase rate	<0.0064 MPag/day (pre-2017 shutdown; 1 Apr – 3 May 2017)	0 MPag/day (27 Apr – 29 Jun 2018)	0.0010 MPag/day (5 Oct – 5 Dec 2018)
Chemistry	Average silica conc. diff. (calculated vs. actual)	<10% (highest SiO2 difference from SMS side stream test using C1; 11 May – 2 Jun 2013)	SP#2 = 3% SP#3 = 0% (2 May – 19 Jul 2018)	SP#2 = 0% SP#3 = 5% (25 Jul – 21 Aug 2018)
	Silica saturation index (SSI)	SSI > 1.0	SP#2 = 0.92 SP#3 = 1.10 (190°C; 19 Jul 2018)	SP#2 = 0.90 SP#3 = 0.94 (190°C; 1 Nov 2018)

In case of unexpected increase in scaling rates (e.g. dosing interruptions, changes in chemistry, etc.), the installed 200 m redundant two-phase line will enable opening and inspection of the original common two-phase line without interrupting operations.

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