

Mechanisms of Erosion-Corrosion in Well 311D, South Sambaloran, Leyte Geothermal Production Field

Erlindo C. Angcoy, Jr., Archibald L. Abarquez, Romeo P. Andrino, Garry F. Cañete,
Melvin D. Lledo, Christine H. Siega and Ruperto R. Villa, Jr.

Energy Development Corporation, Energy Center, Merritt Road, Fort Bonifacio, Taguig City, Philippines

angcoy.ec@energy.com.ph

Keywords: erosion, corrosion, steam-dominated well

ABSTRACT

Well 311D, a steam-dominated production well in Leyte geothermal field discharging suspended solids, manifested erosion-corrosion failures in its wellbore and surface facilities. The suspended solids, initially consisting of formation materials, erode the layer of corrosion products formed when well discharge was still water-dominated. A caliper survey to check its casing integrity calculated a thinning rate of 0.64 mm/yr. Also, its wellhead assembly experienced recurring damage located between the mating flange connection of the expansion spool and master valve and confined along the wingports. The damage is attributed to the combined effects of flow patterns within the wingports, the suspended solids in the flowing stream and any stresses induced by wellhead vertical movements exceeding the design limit. In the branchline, erosion-corrosion is also observed in areas where high heat-loss occurs and in rough edges or protrusions of tapping points' welded portions. Un-insulated facilities in the branchline, act as "heat sinks" forming condensates that absorb corrosive gas species. The mixing of dry well 311D and two-phase well 309D discharges creates intermittent cavitation causing bubbles or mists to collapse in the walls and damage a limited section of the two-phase header within the mixing point.

1. INTRODUCTION

Continuous exploitation of the Tongonan Geothermal Field shifted the discharges of the production wells from liquid-dominated to steam-dominated, manifested by the vertical and lateral expansions of the steam zone (Salonga et al., 2004). The dry well discharges also contained total suspended solids (TSS) >5 ppm. In the absence of an in-situ waterflow to scrub the solids, erosion-corrosion of two-phase and steam lines were initially observed in Tongonan-1 in 2000 (Villa and Salonga, 2001) then expanded to Upper Mahiao in the north and South Sambaloran to the south.

Well 311D was spudded in 1996 as an in-fill large-diameter production well in Pad 300B, South Sambaloran (Fig. 1) drilled to a total measured depth of 2487 m. The well has stable downhole measured temperatures of 250-270°C, is operated at high wellhead pressure of 1.2 MPa and delivers 10-18 kg/s of dry discharge ($H = 2780 \text{ J/g}$) with typical TSS level of 10 ppm (with range of 2-42 ppm). In ~10 years of well utilization, well 311D exhibited numerous erosion and corrosion phenomena from the wellbore to the downstream surface facilities, some of which were not observed in similar dry wells with elevated TSS levels.

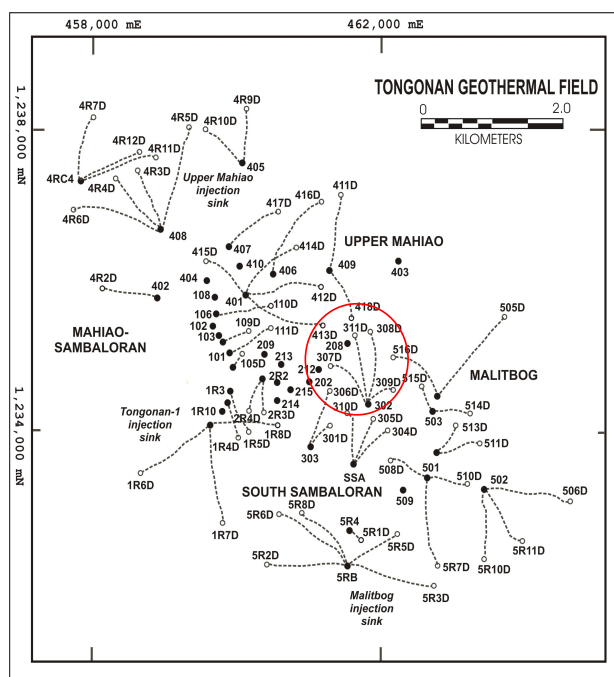


Figure 1: Map of Tongonan Geothermal Field

2. OCCURENCES OF EROSION AND CORROSION

Documented problems in the above-surface facilities connected to well 311D include: (1) recurring leaks and damages of the wellhead assembly, (2) fast thinning in sections of the sweepbend and branchline based on Ultrasonic Thickness (UT) measurements, (3) fast thinning and localized corrosion/pitting in the two-phase header, (5) leaks and damages in flange connections and (6) leaks in tapping points of sampling provisions and bypass line.

2.1 Production Casing Thinning

To determine the wellbore condition, casing inspection by caliper survey was conducted in May 2007 using a 60-arm caliper capable of taking 60 simultaneous inner diameter (ID) measurements at a minimum sampling rate of one data set per 3 inches of tool movement (Buñing et al., 2005). The tool can operate at $T_{max} = 315^{\circ}\text{C}$ and records only the maximum and minimum readings.

Casing thinning calculated throughout the survey depth was 0.2-0.25 inch in its 10 years of utilization (0.64 mm/yr). Thinning worsens as the log goes deeper and as the wellbore deviates. The calculated thinning rate is higher than the acceptable 0.12 mm/yr (3 mm/25 years) but is less than the rates in surface facilities typically at 2 mm/yr in Pad 301 of South Sambaloran (Angcoy et al., 2005) and at 18 mm/yr in Tongonan-1 (Villa et al., 2005). At a consumption rate of 0.64 mm/yr and on the worst scenario that fluid attacked the anchor casing since utilization in 1997, it will take another 2.9 years before critical thickness is reached at 4 MPag internal pressure.

The erosional velocity of the fluid inside the casing was evaluated based on the formula of Salama (2000) for sand-laden fluids (equation 1).

$$V_{erosional} = \frac{(D \sqrt{\rho_m})}{(20 \sqrt{W})} \quad (1)$$

where V is the erosional velocity (m/s), D is the pipe inside diameter (mm), ρ_m is the fluid mixture density (kg/m^3), and W is the sand flow rate (kg/d).

Flow calculations summarized in Table 1 (based on equation 1) show that a 311D total mass flow of 10 kg/s will have a velocity inside the 13-3/8" production casing (7 m/s) exceeding the erosional velocity (6 kg/s) if the TSS level is ≥ 45 ppm. If 311D total mass flow reaches 18 kg/s, then erosional velocity (10 kg/s) is exceeded at a lower TSS level ≥ 8 ppm. Both cases are valid based on historical discharge characteristics of 311D. Thus, thinning of the production casing results from alternate corrosion (between metal and geothermal fluid) and erosion of bare metal and passive films by suspended solids. The suspended solids are initially formation materials that pass through the slotted liner and trigger the removal of protective passive films formed inside the well when 311D water phase was still present. The discharge chemistry of 311D in 1998 when plotted in a Pourbaix diagram shows formation of corrosion products that form the passive films (Fig. 2).

Table 1. Summary of Erosional Velocities in Wellbore.

Casing type	Total Mass Flow = 10 kg/s		Total Mass Flow = 18 kg/s	
	Velocity inside casing (m/s)	Erosional velocity with TSS level	Velocity inside casing (m/s)	Erosional velocity with TSS level
		5 ppm 45 ppm		5 ppm 8 ppm
13 3/8"	7	19 6	12	14 11
9 5/8"	13	14 5	23	10 8

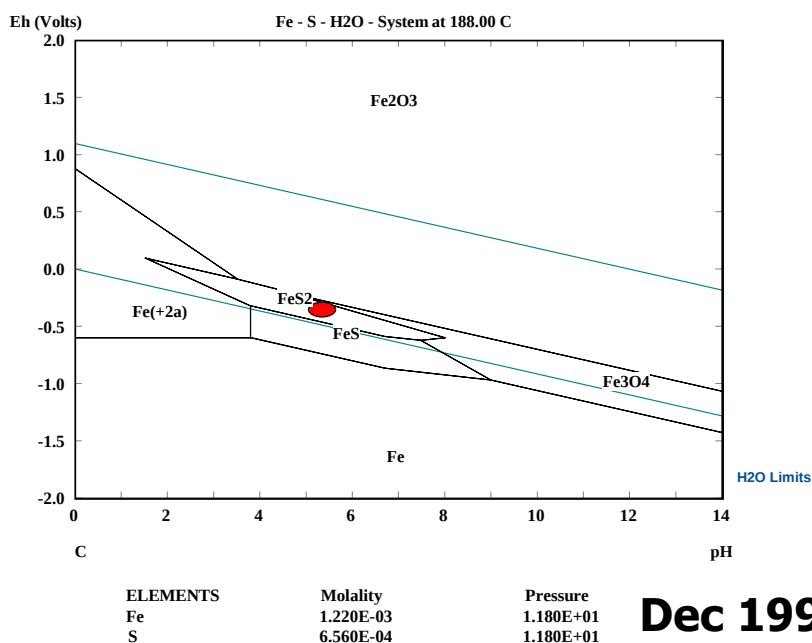


Figure 2: Pourbaix diagram of historical highly two-phase well 311D discharge chemistry.

2.2 Wellhead Assembly Damages

In the wellhead assembly of well 311D, recurring damage was documented in the mating flange connections of the expansion spool and master valve confined along the two opposing wingports (Fig. 3) and could be attributed to the combined effects of flow patterns within the wingports and the suspended solids in the flowing stream. This can be aggravated by stresses due to wellhead vertical movements beyond the design limit that may be experienced during changes in well operating conditions either due to throttling or variations in mass flow. Thus the wellhead assembly leaks were usually observed during preventive maintenance periods.

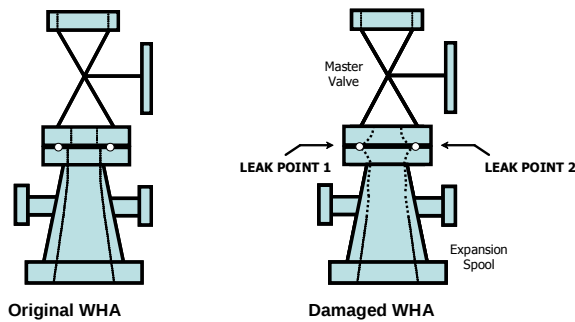


Figure 3: Damages in wellhead assembly (WHA) of well 311D (not drawn to scale).

Flow is altered as the fluid passes through the 3-1/8" diameter wingports that induce eddy currents downstream (Fig. 4). Thus, suspended solids and mists in the fluid are drawn towards the wall and attack the metals downstream and along the wingports. The flange face has a conservative thickness allowance of 3 inches, before metal loss propagates outwards into the groove and the seal ring. At a thinning rate of 0.25 inch/10 yr, no leak is expected to develop in the mating flange connections for a long time provided that the mating flange connections are in static equilibrium. This equilibrium may be upset if the wellhead of well 311D vertically moves above the design limit (± 6 inches) that can induce branchline stresses which can no longer be compensated by pipe support systems. As such, the resulting stressed points along the wingport become vulnerable to erosion-corrosion leading to leaks since a pressure gradient draws the high velocity steam, corrosive mists and suspended solids towards the stressed and worn points aggravating the localized metal losses.

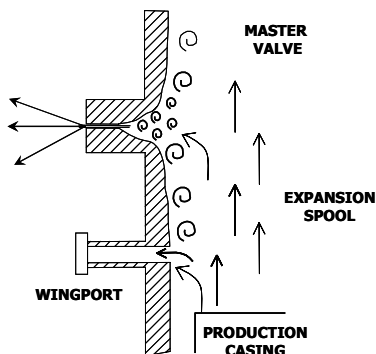


Figure 4: Mechanisms leading to well 311D wellhead assembly damage (not drawn to scale).

2.3 Branchline Leaks

The dominant mechanism of mechanical erosion by suspended solids cause accelerated thinning rates in the sweepbend and the branchline based on UT monitoring data. High thinning rate in the sweepbend is influenced by the angles (10-20°) at which the suspended solids impact the walls. In the branchline, the increased rates are highly correlated with location of high turbulence (i.e., reducer and near the branchline stub-in point to two-phase header). Leaks in the tapping points of bypass lines and vents are due to the combined effects of (1) solids erosion due to turbulence downstream of tapping points (Fig. 5, striking resemblance with the erosion marks downstream of the wellhead assembly wingports) and (2) localized corrosion attack in heat-affected zones (HAZ). HAZ like welded connections underwent changes in properties making them less resistant to corrosion. Rough edges and protrusions inside the tapping points may also be initial points of erosion-corrosion attack.

The entrained water phase of 311D consists of brine mists and steam condensates. Two-phase fluids stagnate in dead legs (between flange connections and in external attachments like sampling points and vents) and condense in these "heat sinks" through convective heat transfer with the surroundings. Condensates conductively cooled below line temperatures (188°C) dissolve more corrosive gaseous species (e.g., CO₂, H₂S, volatile Cl if present) to form acidic solutions. The pH of the nearly-pure condensates declines readily in the absence of the buffering effect of minerals normally present in brine. Water chemistry at line condition was recalculated using the conductive heating feature of WATCH 2.1 from sampling condition (25°C). At 188°C, the Pourbaix diagram indicates a stability area shifted towards the region of uniform corrosion when the solution pH declines to ~4.3 (Fig. 6).

2.4 Two-Phase Header Thinning

The 30-inch diameter two-phase header experienced rapid thinning in a limited section within and downstream of the 311D stub-in point. The severity of the thinning led to the replacement of a 6 m section after ~10 years of utilization. Few scratches/grooving marks in the replaced pipe suggest that the damages are not caused by solids erosion. The internal surface of the replaced pipe showed irregularly-shaped craters either on the metal surface or on the adhering corrosion products (Fig. 7).



Figure 5: Damages in the tapping points of the 2-inch diameter bypass line and 1-in diameter vent viewed from inside the branchline.

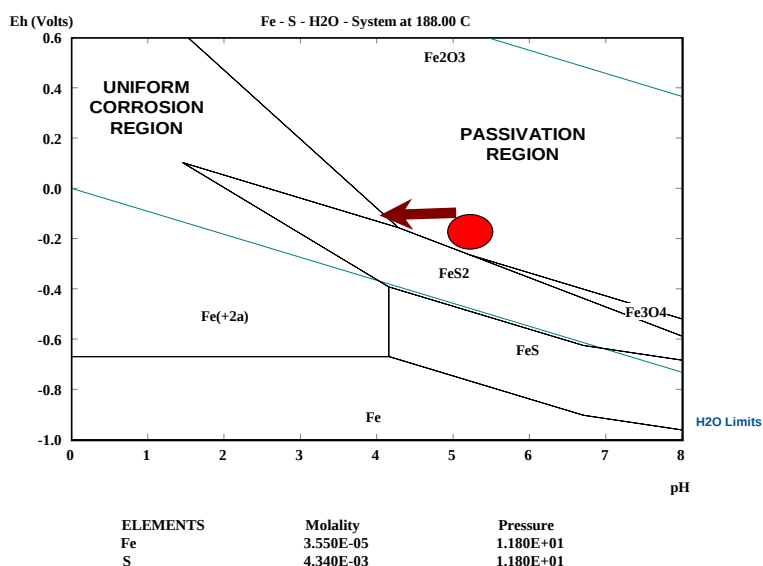


Figure 6: Pourbaix diagram of well 311D condensate chemistry at line temperature (188°C).

This phenomenon is primarily attributed to the effects when the steam-dominated discharge of well 311D mixes with the watery discharge of well 309D. Because of the difference in pipe diameter, a “Bernoulli effect” could occur when a higher velocity well 311D discharge enters the two-phase header. Bubbles or cavities from the water flow of well 309D can be intermittently drawn towards the lower pressure area and rapidly collapse in the upper walls producing a shock wave that dents the metal surface (Fig. 8). After mixing, some steam of well 311D condense and absorb more gas species increasing the corrosion potential of the mixed water phase. Some of the pits in the pipewall initiated by the cavitation effect develop into a local galvanic cell that promotes pitting corrosion and develops into pinhole leaks.

3. CONCLUSIONS AND MITIGATING MEASURES

Well 311D was mechanically cleared and relined to reinforce vulnerable sections of the casing and address the worsening thinning in the deeper part of the production casing based on the caliper survey log. The manageable calculated thinning rate of 0.64 mm/yr in the production casing did not justify installation of a downhole mitigating measure to capture suspended solids from the wellbore. Immediate solutions were focused in addressing the wellhead assembly damages which included lining the vulnerable portions of the expansion spool with abrasive-resistant layer, reinforcement of the flange connections and revisions of pipe support systems to relieve stresses. Future directions are inclined to duplicate the successful hot brine wellhead washing implemented in wells 301D and 306D (Angcoy et al., 2005) since washing through the wingports will mitigate erosion-corrosion from the wellhead to downstream sections by (a) scrubbing suspended solids in steam and (b) buffering the acidity of the water phase due to absorption of more corrosive gas species. All appurtenances attached to the sweepbend and branchline were reviewed for relocation in areas of least turbulence and for insulation to minimize condensation. A limited section of the two-phase header was also reinforced with a higher pipe thickness to anticipate rapid thinning within the mixing points.



Figure 7: Internal surface of the replaced 30-inch two-phase header.

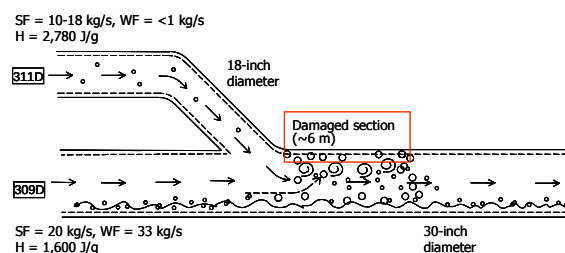


Figure 8: Mixing of wells 311D and 309D discharges.

ACKNOWLEDGMENTS

Sincere thanks to the members of the LGPF Task Force Wellbore Erosion-Corrosion, LGPF Resource Management Department for the spirited exchange of ideas and concerted efforts in tackling the challenges and the EDC management for supporting the publishing of pertinent data.

REFERENCES

Angcoy, E.C., Jr, Alcober, E.H., Ramos S.G. and Rossell, J.B.: Erosion in South Sambaloran FCRS Facilities, Tongonan, Leyte, *Proceedings, 26th Annual PNOC-EDC Geothermal Conference*, (2005), 109-115.

- Buñing, B., Sarmiento, Z., Aleman, E. and Saw, V.: Casing Inspection Caliper surveys: results and implications to operations in Leyte Geothermal Production Field, *Proceedings, World Geothermal Congress 2005*, Antalya, Turkey, (2005), CD, 5 pp.
- LGPF Task Force Wellbore Erosion-Corrosion: Well 311D Erosion-Corrosion Assessment Report, *Internal Report*, (2007), PNOC-EDC.
- Roine, A.: HSC Chemistry 5.0, (2002).
- Salama, M.: An alternative to API 14E erosional velocity limits for sand laden fluids, *Journal of Energy Resources Technology*, (2000).
- Salonga, N., Herras, E., Siega, F., Seastres Jr., J., and Dacillo, D.: Geochemical signatures of the field-wide expansion process of the upper steam zone in Tongonan geothermal field, Philippines, *Geothermics*, **33**, (2004), 109-141.
- Villa Jr., R., Isip, H., Peñaranda, J.R., Salonga, N., Rubin, D., Bontia, U.R., and Saw, V.: Methods of removing solids from the discharge of steam dominated wells in Leyte Geothermal Production Field, Philippines, *Internal Report*, (2005), PNOC-EDC.