

## SURFACE EQUIPMENT AND SUB-SURFACE CASING CORROSION AND EROSION - THE CASE OF BL-1D, SOUTHERN NEGROS GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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### ABSTRACT

*Corrosion of both surface and sub-surface equipment has been a perennial problem in the commercial operation of the Palinpinon Geothermal Field. Acidic discharge either inherent or induced by prolonged exploitation of the field is the major cause of corrosion that triggers not only the undue replacement of the wellhead assembly components but also the excessive thinning of the wellbore casing. The severity of corrosion varies from well to well depending largely on the chemical characteristics of the discharging fluids.*

*At least 10 from a total of 39 commercially producing wells in Palinpinon are affected by acid intrusion and have been the subject of continuous chemical monitoring, particularly the pH, SO<sub>4</sub>, Mg and Fe levels. Of these, PN-20D, PN-22D and BL1-D showed higher thinning levels based on Ultrasonic Test (U.T.) measurements and Casing Inspection Caliper (CIC) surveys. The corrosion attack was so severe in well BL-1D that the production liner eventually parted just below the PCS. Compounding this problem was the erosive action of the corrosion products and suspended solids consisting of minute formation particles entrained in the discharging fluids.*

*Despite the low pH of and high Fe concentration in the discharging fluids, well BL-1D was utilized for commercial operation almost continuously for over six years since its commissioning in November 1994. Within this period, a number of operational interventions, e.g. spring water injection and the adoption of the sweep bend section into the wellhead assembly, were implemented to address the problem on high iron levels and excessive thinning of the wellhead tee.*

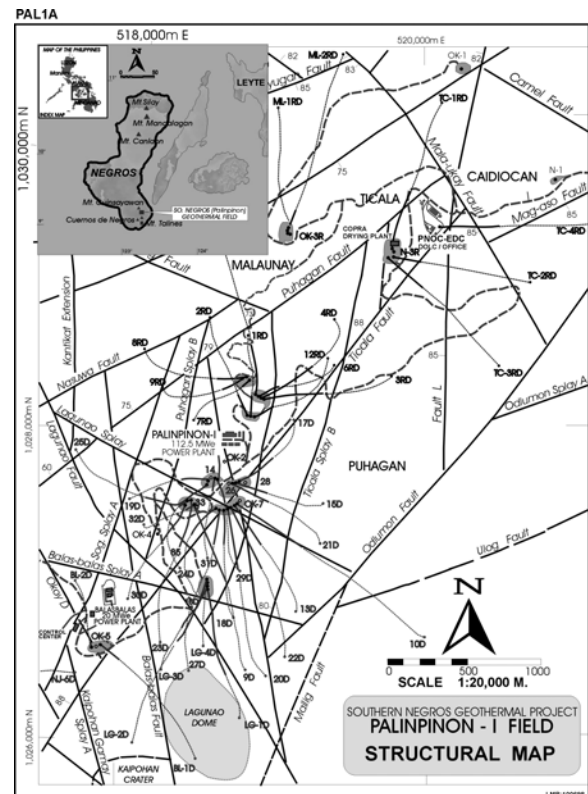


Figure 1. Location and structural map.

### 1.0 INTRODUCTION

BL-1D was drilled from the Balasbalas sector of the Palinpinon - II production field of the Southern Negros Geothermal Project to a total depth of 2693.5 mMD (2419.4 mVD), and completed on October 26, 1990. Deviated towards the Lagunao Dome, the open hole of the well intersected a liquid-dominant feed zone from 2200 mMD to the bottom, and the inferred steam cap just below the production casing shoe (PCS) to the major two-phase feed zone at 1400 – 1600 mMD (Figure 1).

The well was commissioned in November 1994 to augment steam supply to the 20-MWe OK5

Modular Power Plant. It had been utilized almost continuously for over six years until it was relegated as a standby production well in May 2001 after its replacement with BL-3D.

The discharge fluids from the well had initial pH level between 4 to 6 but this declined to as low as 3.5, accompanied by an increase in iron concentration shortly after its commissioning. The corrosion/erosion which was observed at the silencer and discharge spool immediately after the well's medium term discharge (MTD) test prompted the subsequent thickness monitoring of the wellhead tee, elbow and production casing that lasted almost throughout the duration of its discharge to the power plant.

**2.0 WELLBORE BLOCKAGE HISTORY**

The Medium Term Discharge (MTD) output of the well in 1991 reached ~13 MWe but was reduced to ~11 MWe when the well was commissioned in 1994 due to localized pressure drawdown. The occurrence of a wellbore blockage tagged by an 80 mm diameter GD at around 1700 mMD on February 1996, which progressed to ~1100 mMD on June 25, 1997 further reduced this to 10 MWe and finally to 6.7 MWe (Table 1). Scraper runs conducted on June 25, 1997 and January 10, 1998 yielded significant amounts of corrosion products and formation cuttings. The corrosion products were indications of the severe corrosion occurring in the upper section of the 7-5/8" slotted liner while the accompanying formation cuttings envisaged the possibility of a liner break (Table 2).

The formation of the wellbore blockage at ~1100 mMD effectively isolated the "wetter" feed from the bottom zone, leaving the two-phase upper feed to dominate the discharge. It was earlier believed that the acidic discharge originated from the bottom zone (Bayon, 1995) and that the wellbore blockage was thought of as beneficial as it supposedly suppressed the acidic contribution from the bottom zone. However, later evaluation of the mechanism and origin of BL-1D's acidic discharge (Vidal, 1998) proposed that the source of the acid fluids, formed by the conversion of H<sub>2</sub>S to H<sub>2</sub>SO<sub>4</sub>, came from steam-heated perched aquifer at the shallow zones. Hastened by pressure drawdown, these acid fluids percolated down and entered the well via the upper two-phase feed zone. This was confirmed with the

Table 1. BL-1D FBD BOM data before and after the 1998 mechanical workover.

Date (dd/mm/yy)	Enthalpy (kJ/kg)	Mass Flow (kg/s)	Water Flow (kg/s)	Steam Flow (tph)	MWe
07 Aug 91	2504	31.4	4.1	98.6	13.1
05 May 94	2362	29.3	4.1	84.9	11.3
04 Aug 94	2617	22.6	0.6	75.7	10.1
23 May 97	2347	19.5	2.8	56.1	7.4
18 Sep 97	2548	15.6	0.9	50.4	6.7

Table 2. BL-1D blockage history.

Date Surveyed (dd/mm/yy)	Tagged Depth (mMD)	Instrument Size
31 Jan 96	2600	32 mm Ø SB
02 Feb 96	1713	80 mm Ø GD
25 Jun 97	1105	80 mm Ø GD
10 Jan 98	1152	80 mm Ø GD

observed elevated Fe concentration in the last quarter of 1997 and first two months of 1998, and the work-over results of this well in mid-June 1998.

**3.0 WELLHEAD ASSEMBLY THICKNESS MONITORING RESULTS**

The wellhead tee and elbow thickness monitoring started shortly after the MTD test of the well. The excessive erosion at the discharge spool and the silencer, and the relatively high magnesium and iron concentrations of 3 ppm and 14 ppm, respectively prompted the UT measurements. The results of these early measurements however, indicated no dramatic reduction in thickness of these surface equipment, obviously as the discharge duration of the well's MTD was relatively short. Hence, it was concluded at that time that the impinging high velocity fluids caused the excessive erosion on the discharge spool and silencer.

Wall thickness measurements resumed shortly after the wellhead tee was replaced on January 13, 1997. Measurements were taken across the cross-sectional area (designated by letters, Figure 2) and along the length (designated by numbers, Figure 2) of the wellhead tee, elbow and upper section of the 13-3/8" anchor casing.

UT measurements of the 14"- wellhead tee within a fifteen-month period from January 1997 to March 1998 indicated that all points of section "B" (Figure 3) showed consistent and highest thinning. Exponential increase in the corrosion

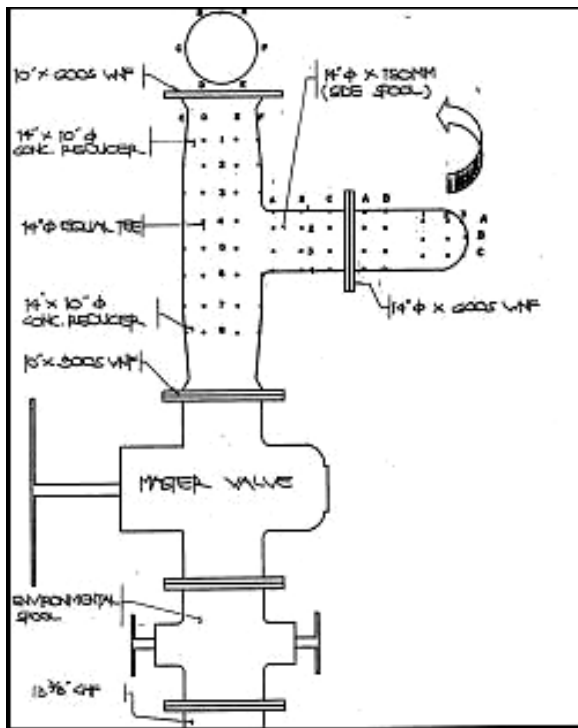


Figure 2. Wellhead tee and elbow (after Silorio, 1997).

rate was observed from an initial of ~1 mm/month prior to the second replacement to 5.3 mm/mo. and 2.6 mm/mo. prior to the third and fourth replacements. Replacement of the wellhead tee was based on an allowable minimum pipe wall thickness of 7.7 mm computed (using ANSI B31.1 equation) for an operating pressure of 0.76 MPag of the well. A slightly higher value of 11.5 mm was established for a shut-in pressure of ~3 MPag. The corrosion rate was highest prior to the third replacement as only a re-built wellhead tee was used. Accelerated thinning was also observed at the 14" inch elbow particularly in section "C", but unlike the wellhead tee, repairs were made to extend its service life. In both equipment, the excessive thinning generally took place where the flow direction of the discharging fluid changes from vertical to horizontal.

The accelerated thinning at section "B" of the well head tee and section "C" of the 14" elbow took place in time with the changes in the line chemistry of the well and the progression of the wellbore blockage from ~1700 mMD to ~1100 mMD. The line pH (Figure 4) dropped abruptly from an average of about 4.5 in the 1<sup>st</sup> quarter of 1997 to 3.0 – 3.5 in April 1997 that continued on to the first two months of 1998. Conversely, the total Fe concentration level (Figure 5) increased steadily from <20 ppm in March 1997, to 30 ppm - 40 ppm before it peaked to a high of almost 100 ppm in March the following year. It was earlier surmised that iron levels entrained in the discharging fluids were coming from the eroded wellhead assembly and surface pipeline. However, the elevated iron levels from October 1997 to February 1998, notwithstanding the installation of fully re-built tee on 27Nov97 and new wellhead tee in 9Jan98 suggested that these iron particles were coming from the wellbore. Also, the parallel occurrence of the accelerated thinning and the increase in iron concentration strongly implied the latter as the major cause of the former.

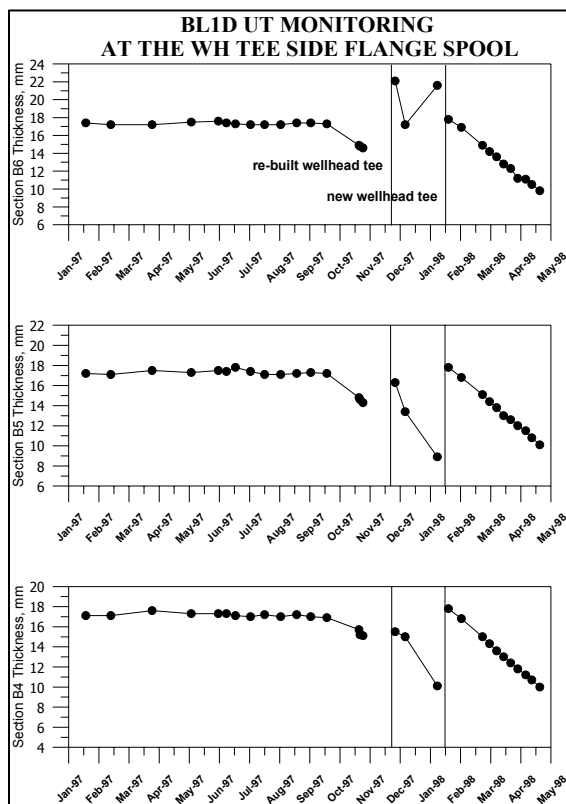


Figure 3. BL-1D thickness monitoring trend.

#### 4.0 CASING INSPECTION CALIPER SURVEY RESULTS

Excessive wall thinning of the production casing is perhaps the most critical condition that can result from the corrosive and erosive characteristics of the discharge fluid from a production well. In extreme situations, severe

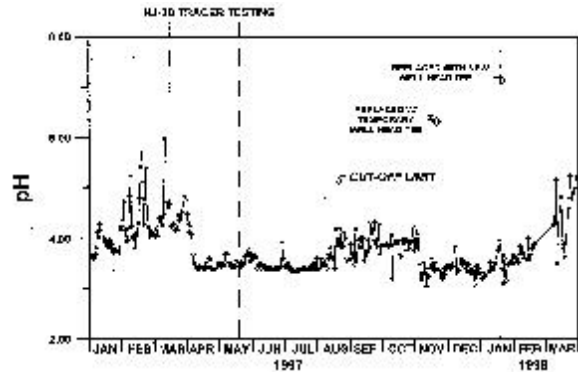
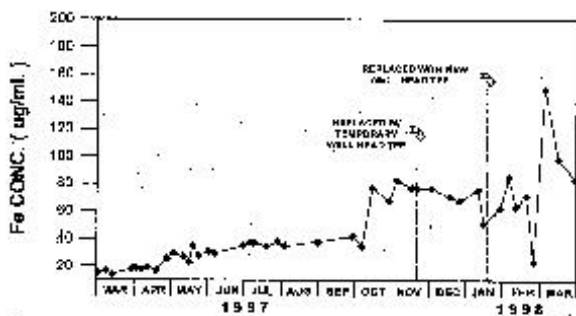


Figure 4. BL-1D line pH trend (after Quevenco, 1998).



BL1D Fe (Iron) CONCENTRATION vs. TIME

Figure 5. BL-1D iron concentration with time (after Quevenco, 1998).

metal loss from the casing wall could lead to an uncontrolled discharge, as in the case of well AP-6D in Alto Peak, Leyte Geothermal Power Project.

Thus, the severity of the UT-measured metal loss in the wellhead assembly of BL-1D, PN-20D and PN-22D prompted the subsequent CIC surveys in these wells. The initial surveys were conducted to serve as baseline measurement and at the same time to determine the extent of damage in the production casing. Subsequent surveys were done to determine the rate of metal loss in the casing so that remedial actions can be taken at the proper time. In the case of BL-1D, the results of this first CIC survey conducted in June 25, 1997 indicated no significant reduction in the production casing wall thickness.

At the height of the corrosion attack in BL-1D between the last quarter of 1997 and 1st quarter of 1998, when the elevated Fe concentration was established to originate from inside the

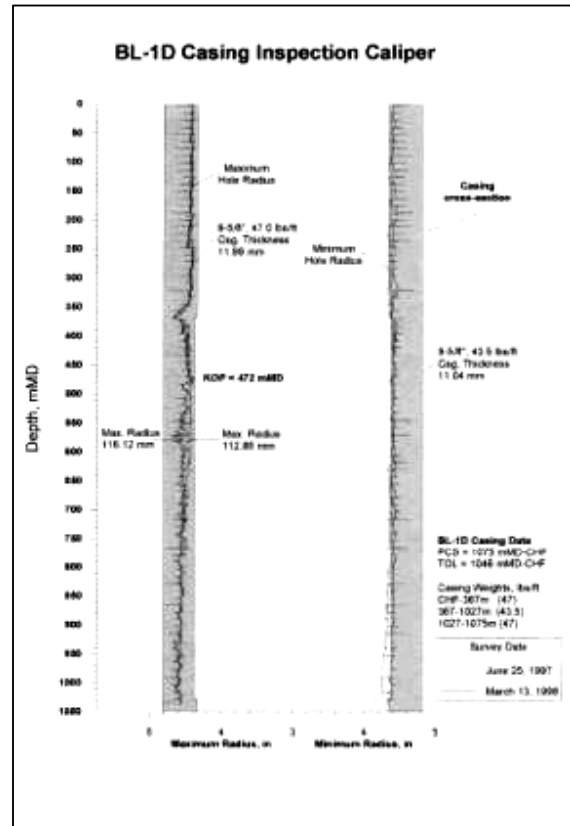


Figure 6. BL-1D composite plot of CIC results.

wellbore, a repeat casing inspection caliper survey was conducted on March 13, 1998. The objective was to check the casing wall thickness and the over-all integrity of the 9-5/8" production casing in preparation for the mechanical workover being considered at that time. The results positively identified the section between 460 mMD and 650 mMD to have appreciable yet un-circumferential thinning as evidenced by the composite plot of the June 25, 1997 and March 13, 1998 survey logs (Figure 6). The maximum radius measured at 576 mMD increased from 112.85 mm (June 1997 log) to 116.12 mm (March 1998 log) indicating a thinning rate of 3.27 mm over a 9-month period, which is consistent with the thinning trend at the wellhead tee and elbow. At a linear rate of corrosion, the well can further be utilized for about one year before the thinned-out section of the production casing would be eroded completely.

## 5.0 MECHANICAL WORKOVER RESULTS

The worsening acidity of the discharge and corrosion of the well, corroborated by geochemical and physical data, warranted the mechanical workover of the well from June 28, 1998 to July 7, 1998. The primary objectives of the mechanical workover were to reline the thinned-out section of the 9-5/8" production casing at 650 mMD, and to drill-out the blockage at the 7-5/8" slotted liner. Opening up of the bottom zone anticipated contribution from the more neutral, liquid-dominated feed and thus, abate the acidity of the total discharge.

Unfortunately, the workover objectives were not achieved due to unfavorable downhole conditions. The top of the 7-5/8" liner was tagged at 1090.5 mMD, about 44 meters below its original depth of 1046.9 mMD, creating a 15 meter gap of open hole between the production casing shoe which was set at 1075.6 mMD. In addition, a liner break existed at 1214.5 mMD leaving the upper and lower section off-centered. The rig was able to clear the slotted liner at the vicinity of the major permeable zone up to 1556.5 mMD but a hard obstruction at this depth prematurely terminated the workover operation. Relining of the thinned out section of the production casing was also foregone due to technical difficulties associated with this activity (Figure 7).

The results of the injectivity and pressure fall-off tests – conducted inside the production casing – that followed were also deemed unreliable due to effects of collapsing steam. The subsequent bore output measurements indicated no significant change from the pre-workover output between 6 MWe to 7 MWe. Despite the failure of the mechanical workover to improve the well's output, it was able to provide information on the actual downhole condition and possible origin of the acid source, and the mechanism of the corrosion/erosion happening on the well.

## 6.0 MITIGATING MEASURES EMPLOYED DURING BL-1D COMMERCIAL OPERATION

In view of the problems on high iron level and excessive erosion, mitigating operational measures had been implemented. Prominent among these were the fresh water injection system and the adoption of a sweep bend into the wellhead assembly. The former was initially

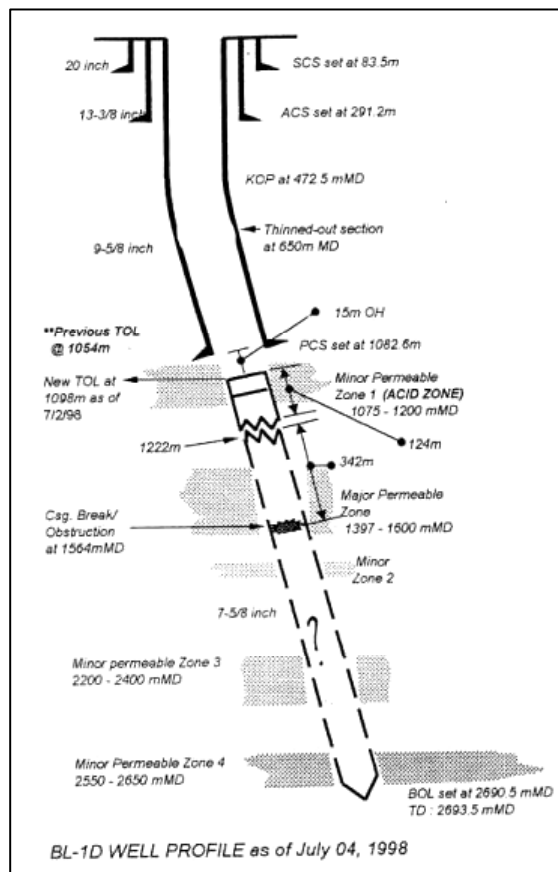


Figure 7. BL-1D casing profile after aborted mechanical workover (after Retuya, 1998)

employed to facilitate steam acceptance to the power plant while the latter was designed to minimize the cost of wellhead tee replacement.

Steam blowing prior to the well's commissioning indicated a relatively high content of total suspended solids (TSS) entrained in the steam flow evidenced by abrasion marks on the target plate. Spring water injection at the two-phase line through the bleed line was conducted to reduce TSS carry-over in the steam flow (Figure 8). By principle of adhesion, the suspended solids were weighed down and separated from the steam going to the turbines. Heating of the spring water was also carried out to remove dissolve oxygen from the spring water, and to minimize the cooling effect on the two-phase fluid during injection. Water injection facilitated BL-1D steam acceptance to the plant in October 1995 and was continued until it was terminated in 1996 when TSS level had diminished when the well's discharge became dry.

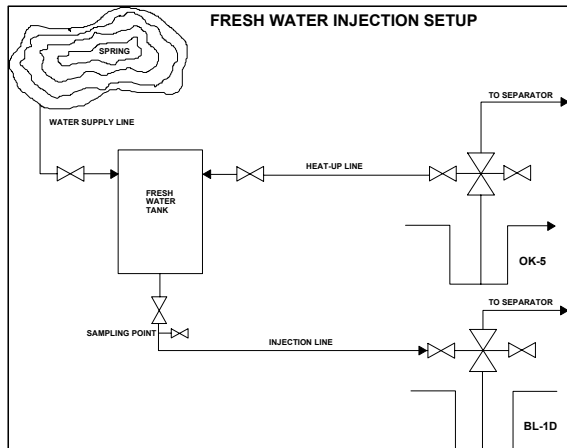


Figure 8. BL-1D fresh water injection set-up.

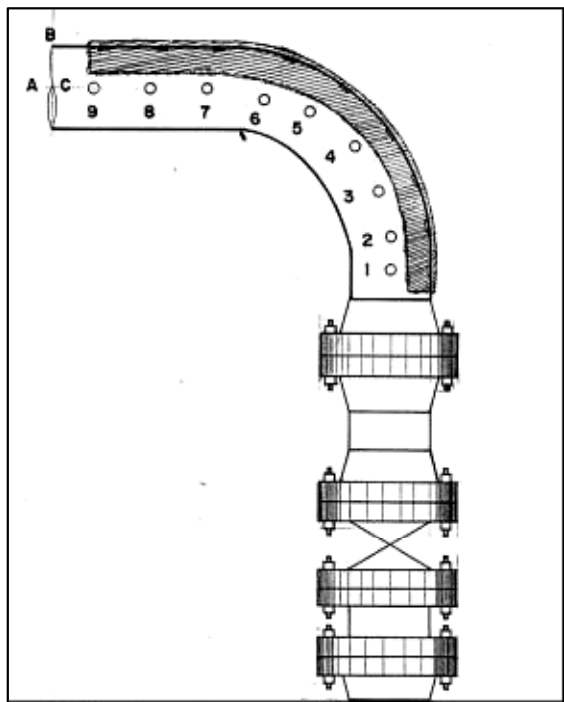


Figure 9. BL-1D Sweep "S" Bend Section (after Catacutan, 2000).

The frequent and the narrowing interval of replacement of the wellhead tee had rendered the operation of the well no longer cost effective not to mention the loss opportunity brought about by the frequent well shutdown. Thus, after the aborted mechanical workover, the wellhead configuration was revised to adopt a sweep bend atop the master valve (Figure 9). The re-configuration of the wellhead shifted the point of excessive corrosion and erosion from the expensive wellhead tee to the relatively cheaper sweep bend. Like the wellhead tee, the

section with severe erosion was found at the points where the flow direction changes. But unlike the frequent replacement of the wellhead tee, welding of a metal jacket around the thinned out section can extend the service life of the S-bend.

Other short-term interventions implemented included the replacement of the thinned out wellhead tee, welding of the outer walls of the 14" elbow and installation of metal jacket on the S bend. Re-lining of the thinned-out section of the production casing was also considered but was aborted due to unfavorable downhole conditions. However, all these served only as stopgap solutions designed to sustain the commercial operation of BL-1D but fell short in putting a complete stop to the recurring problem. Opening-up of the feed zone at the bottom would have made a lasting solution had the mechanical workover succeeded in clearing the wellbore blockage. Contribution from the neutral, liquid-dominated feed at the bottom zone could have minimized if not eliminated the problem of surface and sub-surface erosion.

With the technical difficulties associated with the full rehabilitation, and the high cost, not to mention the risk, involved with the continued utilization of this well, a make-up and replacement well was eventually drilled to take the place of BL-1D.

## 7.0 INTERPRETATION OF THE RESULTS AND DISCUSSION ON THE IMPLICATIONS

The physical and chemical data provided a cause-and-effect relationship of the corrosion and erosion happening in the well but it was perhaps the downhole information gained from the aborted mechanical workover that finally put all the pieces together into a logical and acceptable explanation. While the collective results of the bore output measurements, line chemistry, and GD/SB/CIC runs had as much established erosion as the major cause of the accelerated thinning, and the source of the iron particles responsible for the erosion, it was the findings of the clearing assembly that identified the upper zone as the most likely location of the acid inflow. The missing ~44 meters of the slotted liner signified the complete corrosion/erosion of this section, and strongly pointed to this as the undisputed source of the

iron particles. Finally, it was the results of the aborted mechanical workover that confirmed how extensive the corrosion and erosion had occurred in the wellbore.

Even without the relining of the thinned-out section of the 9-5/8" production casing, the well can still be used for over a year of continuous steam production assuming a linear erosion rate. However, it would entail considerable economic consequence in terms of frequent shutdown of the well for sweep bend repairs and casing caliper surveys to monitor the casing thickness. A far more serious consequence would be the certainty of an uncontrollable blowout of the well starting off at the sub-surface once the casing wall fails. The subsequent damage to the OK5 well pad will result to substantial loss of opportunity as it will interfere with the power generation of the OK5 Modular plant, as well as that of Nasuji and Sogongon Modular plants, which are situated further up. In view of this, extreme caution must be applied should BL-1D be re-commissioned, if at all.

Despite the relatively short service life of the well, revenue versus cost evaluation would easily show the profitability of utilizing this well for steam generation. BL-1D had been on-line to the OK5MP fluid collection and disposal system (FCDS) for a total of ~46,000 hours since commissioning, logging an equivalent of ~5 years of continuous commercial operation before it was finally shutdown and relegated as a standby production well in May 2001.

The case of BL-1D showcased the viability of utilizing acidic wells for steam production. Improved well designs however, could prolong the service life of acidic wells and minimize operational cost. If possible, the production liner should be reinforced with corrosion resistant materials at the kick-off point (KOP) where change in the fluid flow from vertical to horizontal occurs and in sections where dogleg-severity is high. The sweep bend should also be adopted and reinforced with corrosion resistant material.

Based on the BL-1D experience, thorough monitoring of the physical and chemical parameters is very important in managing the operation of acidic wells. Early resolution of the mechanism and origin of the acidic discharge is deemed prudent in the formulation of relevant interventions.

## 8.0 SUMMARY AND CONCLUSIONS

The acidic discharge of well BL-1D, aggravated by the relatively high iron concentration, triggered the corrosion and erosion at the wellhead tee, 14" elbow and the 9-5/8" production casing. The formation of a blockage in the well which suppressed the WO identified the Fe to be coming from the upper zone, but did not prove the neutrality of the bottom feed worsened the acidity of the well's discharge and set off the complete corrosion/erosion of the upper ~44 meters of the 7-5/8" slotted liner. The ensuing corrosion products entrained by the discharging highly two-phase fluids caused the accelerated thinning of the wall thickness of the above mentioned equipment that led to the frequent replacement of the wellhead tee, and prompted the conduct of the mechanical workover.

The mitigating operational interventions, e.g. spring water injection and the re-configuration of the wellhead tee, were employed to ensure the commercial operation of the well but these fell short in completely solving the problem on the elevated iron concentration and excessive thinning of the wellhead tee. Opening of the bottom zone, which would have allowed contribution from the more neutral and liquid feed could have abated the worsening acidity of the well's discharge, but was not pursued due to technical difficulties associated with it. As such, a make-up and replacement well was drilled to replace BL-1D.

Even with the de-commissioning of BL-1D, the well was still able to profitably generate steam for the power plant based on revenue versus cost evaluation, attesting to the economic viability of utilizing acidic wells for steam production notwithstanding the accompanying operational difficulties. The service life of the well could still be extended by at least one year. However, its economic and safety impacts should be carefully considered as it could seriously jeopardize not only the OK5 Modular plant but also those of the Nasuji and Sogongon modular plants.

Finally, the experience gained from BL-1D corrosion and erosion provides valuable information in dealing with similar situations in the future averting a possible repeat of what happened in BL-1D.

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