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Addressing the Problem of Decreased Capacity of an Injection Well Due to Accumulation of Debris - the Experience in Well KN1RD, Philippines

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ABSTRACT

Since the onset of operation of Mindanao 2 Geothermal Power Plant in Mindanao, Philippines, waste brine injection has been a challenge. Having initially only one re-injection well KN1RD available to dispose of all the wastewater from 7 production wells with a total brine flow of > 300 TPH, the injection capacity of the well has been critical.

Solids entrained in the discharge of Mindanao-2 production wells cause solids accumulation in Pad C Main Brine Line (MBL2) solids traps and re-injection well. This necessitated five mechanical workovers using a drill rig and an acidizing job on KN1RD, in the past 9 years. In addition to workovers, other mitigating measures employed are: installation of solids collector in production well two-phase line, relocation and reconfiguration of the solids trap, installation of a redundant injection line to KN1RD, brine pumping, drilling of additional re-injection well and regular cleanout of solids traps. These measures achieved only partial and temporary successes since these do not address the main problem of discharge of solids from the production wells. The source of the solids in Pad C brine line is well KN3B based on the petrography of the solids collected.

This paper outlines the steps undertaken through a multi-disciplinary approach to identify the problems associated with the recurring injection capacity decline in KN1RD and the remedial actions employed to address the problem. Also discussed are the technology frontiers that maybe pursued in the future to solve similar problems in other fields.

1. INTRODUCTION

Mindanao-2 geothermal power plant (M2GPP) is the second geothermal power station in Mindanao Geothermal Production Field operated by Energy Development Corporation (EDC) in the island of Mindanao in the Philippines (Figure 1). Mindanao-2 was commissioned in June 1999 with a base load capacity of 52 MW. The plant is a dual (high pressure-low pressure) flash type. High-pressure steam that flows at a rate of 340 TPH is supplied by nine production wells. The turbine inlet pressure of the high-pressure steam is 7.0 bar abs. Low-pressure steam comes from second flash of the separated water from adjacent Mindanao-1 high-pressure separators. Turbine inlet pressure of low-pressure steam is 4.4 bar abs. and flows at a rate of 47 TPH.

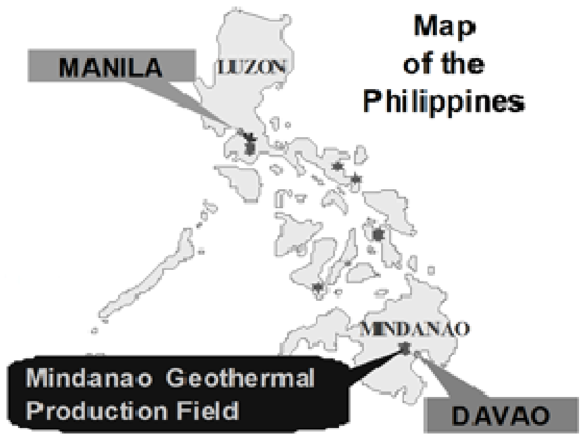

Figure 1 Location of Mindanao Geothermal Production Field, MGPF in southern Philippines.

Steam supply for M2 geothermal power plant (M2GPP) comes from 9 production wells from 3 pads. Two of these pads hold 7 production wells and deliver two-phase fluid to 2 x 25 MW central steam/liquid separator station in Pad C. The separator produces a maximum of 324 TPH of brine when all 7 production wells are producing at their maximum output (Figure 2).

The brine from this separator is re-injected initially to a single well called KN1RD at a temperature of 170°C. The injected brine is acidic with pH ranging from 3.2 to 5.5 and silica concentration typically in excess of 1,000 ppm. Occasionally, brine from the separator has to be diverted to holding sumps when its flow rate exceeds the capacity of injection well. The brine is allowed to cool to 30-40°C in the sumps before being injected to cold re-injection wells along with the power plant blow down.

The accumulation of solids in Pad C Main Brine Line (MBL2) solids trap (ST) and KN1RD was caused by solid debris entrained in the discharge of Mindanao-2 production wells. This is a recurring problem that probably started in 2000 barely a year after the commissioning of M2GPP in 1999. Solids that are not captured by the traps installed along the re-injection line eventually enter the re-injection well causing decline in brine acceptance with time. Injection capacity of KN1RD reduces to zero in as little as 8 months after a clean-out by a drill rig.

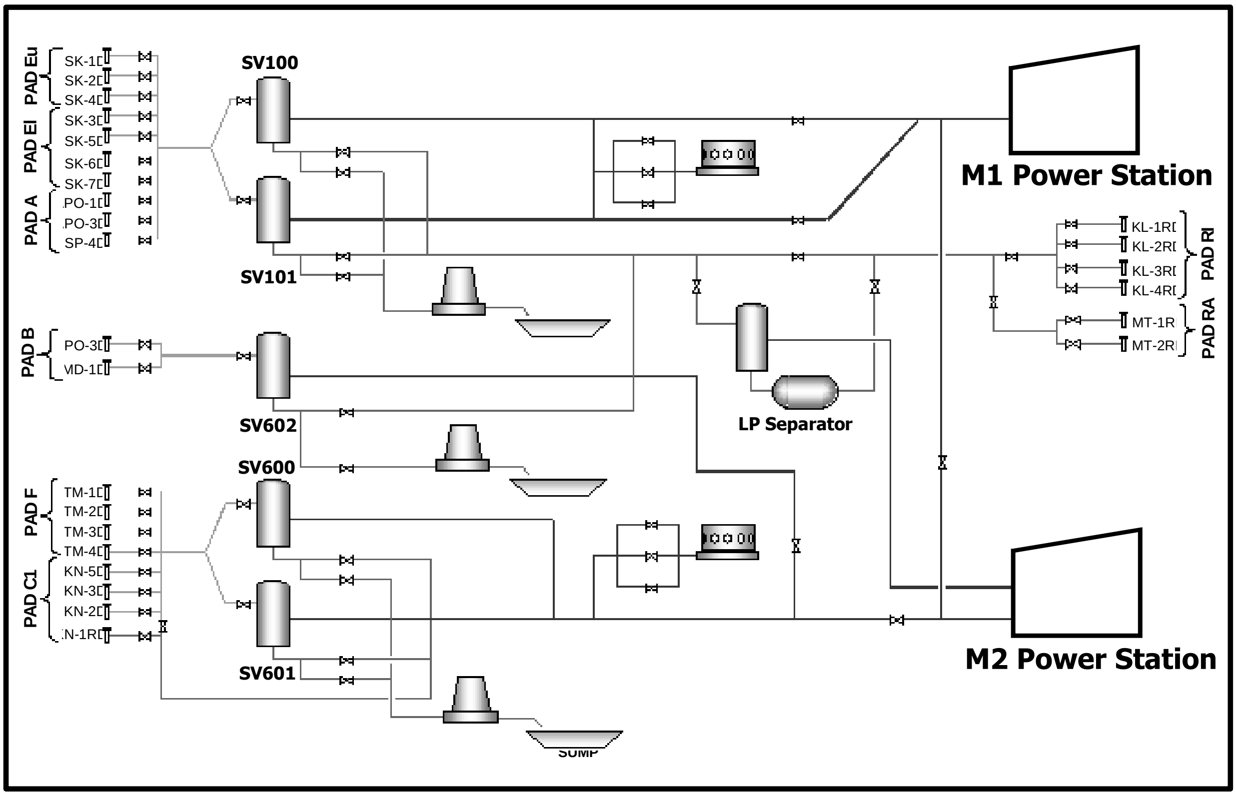

Figure 2. This is a schematic diagram of M1 and M2 fluid collection and re-cycling system (FCRS). Mindanao-2 employs a low pressure and high pressure separator system. Separated brine from SV 600/601 is injected to well KN1RD.

It was initially postulated that the decline in capacity of the well was due to silica scaling because of the high silica oversaturation of the injected brine. It was also argued that the reduction in injection capacity is caused by the natural permeability limitations of the well. The decline was not attributed to solids accumulation because of the absence of any solid particles in the traps from the inspections conducted in early 2000.

This paper outlines the measures employed by EDC to address the recurring injection capacity decline in KN1RD and the steps undertaken to identify the cause of the decline.

2. MITIGATING MEASURES

2.1 Mechanical workover and acid stimulation of well KN1RD

Five workovers using a drill rig and an acid stimulation were conducted over the past 9 years in well KN1RD after commissioning of Mindanao-2 to regain fluid acceptance and recover permeability during its utilization as injection well.

Well utilization in Mindanao-2 (M2) diagram in figure 2 illustrates all six production wells (PW) were online at the onset of production except for a short interval where well TM1D was cut-out in December 1999. Well KN5D was cut-in September 2000. Pre-commissioning flow tests of well KN1RD established the initial injection flow at 60-65 kg/s at the onset of M2 production in July 1999. Injection flow stabilized at 60-62 kg/s until November 1999 and began to decline in the succeeding months to 35 kg/s until April 2000 (Trazona, 2002). Correspondingly, at the onset of decline in injection flow brine from the M2 separators were being dumped and coursed through an open canal to the brine sumps. As much as 15-18 kg/s dumped brine flow was measured along the C-canal. However in May 2000, flow measurements indicated an increasing trend in injected brine flow with corresponding decline in dumped brine following changes in well utilization. The trend continued until late July 2000 where well KN1RD improved again to its initial injection flow of 60-62 kg/s. Following August 2000, injection flow again began to slightly decline and appeared to have sustained an injection flow under 60 kg/s for over six months until February 2001 and even indicated an increase in March 2001. During this period very minimal dumping or none was monitored while wells TM1D and TM2D were alternately utilized upon the completion and cut-in of well KN5D. However, dumping again developed by mid-April 2001 progressing in excess of 20 kg/s. Flow measurements conducted in May indicated a decrease in injection flow to KN1RD at 40 kg/s. This flow appeared to stabilize until October but further decreased to 35 kg/s and finally in December to 5 kg/s. At the time the well ceased to accommodate brine from the production wells, wells TM1D and TM2D were also cut-out from the system to contain excess brine dumping leaving wells KN2D, KN3B, KN5D, TM3D and TM4D to supply steam to the system.

The fourth workover and acid stimulation in well KN1RD was conducted in May 15, 2002 and completed by May 26, 2002 after a series of technical evaluation proved solids accumulation and possible mineral deposition diminished the acceptance. Injection capacity was regained to 123-134 kg/s with the clearing of debris from the well The injectivity index calculated was 29-36 li/s-MPa. Acid stimulation on the other hand pushed further its injection capacity to potentially 234-250 kg/s with an injectivity index of 86-139 li/s-MPa (Table 1).

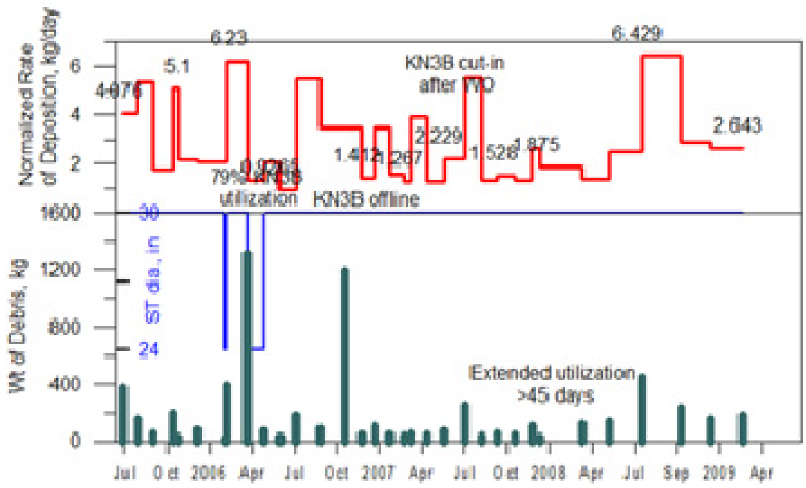

Figure 3. The average rate of solids deposition in Pad C MBL solids traps is 5 kg/day. High rates of solids accumulation observed co-inside with post maintenance shutdown of the power plant where most of production wells are re-discharged after a brief shut-in period.

A total of 24 cubic meters of debris was removed from the well composed of rock fragments, corrosion products and mineral scale components (Figure 3).

Figure 4. Solids discharged by the well and collected from the solids trap consists mostly of formation rocks with small amounts of corrosion products and silica scales. Silica forms a thin layer around the solids which binds the solids together. The petrology of the rocks gave a clue to the source production well.

The well was immediately put on line after completion of the workover and acid stimulation. Injection began with 81 kg/s. In barely 7 months of utilization however, injection flow to well KN1RD again declined to 40 kg/s with production wells TM1D and TM2D utilized (Figure 2). Correspondingly, brine dumping began when injection flow to KN1RD began to decrease. This led again to another workover to clear-out solids debris in the well. The fifth workover was done in April 6 to 20, 2004. The results indicated that injectivity index was regained to 33-35 l/s-MPa or an equivalent injection capacity of 137-140 kg/s.

Table 1. KN1RD has undergone five mechanical workovers since commissioning with one combined with an acidizing job. The fill consisting of rock particles not captured by the solids trap end up at the bottom of the well preventing the major feed zone at the bottom from accepting brine.

	Date	**Max. Clear Depth, m.**	**Injectivity Index (L/s – MPa)**	**Debris Fill, m.**	**Flow, kg/s**
Post Drilling	April 1993	2,193	35		
WO 3	April 1998	2,172	11	21	60
WO 4/acid	May 2002		36 / 139		81
WO 5	April 2004	2,080	34.6	113	71
WO 6	March 2006	2,063	20	130	42
WO 7	March 2008	2,169	31	24	65

The results of the technical evaluation done prior to the workover and acid stimulation suggested that solids from well KN5D may have contributed to the decline in permeability. Furthermore, mineral deposition may have set-in the well bore. The solids debris removed from the well consisted of 50-80% rock fragments, 15-40% corrosion products and ~10% amorphous silica. The rock fragments consisted of microdiorite, diorite/monzodiorite, quartz-biotite andesite and dacite(Dulce, 2001) (Figure 4). Although weakly altered, these rocks show a high-temperature alteration assemblage consisting of biotite, euhedral epidote, chlorite and anhydrite. The foregoing assemblage is found in KN3B as this is the only well that intersected microdiorite dikes at depth (2500-2650 meters) strongly implying the major source of debris came from this well. Apart from the dominantly rock fragments removed from the borehole after workover, corroded metal fragments were also recovered from the solids trap. The metal fragments were suspected to be break-off pieces from the 9-⅝" diameter liner or casing based on its configuration where the casing threads are like those found in 9-⅝" perforated liners are visible. Downhole surveys conducted in well KN3B confirmed the liner break located between depths 2500 and 2650 meters. The altered andesite and dacite however are also intersected in the other production wells such that these wells are believed to also contribute solids in the discharge. The comparison of the blockage tagged in well KN1RD at 1940 meters composed of large rock fragments in 2002 to sand-sized silica scale fragments in 2004 on the other hand provided the following evaluation: increased efficiency of the solids trap and rock fragments may have not been completely removed during the fourth workover. Mineral deposition was also predicted to have set-in the well following the injection trend characteristics and the gel-like debris tagged in the wellbore. The trend also suggests other wellbore processes taking place such as discharge cycling as in the case of KN2D and KN3B. Cycling behavior as observed in Mindanao-2 production wells would result to either increase or reduction in water flow that seemingly induce an increase or reduction of acceptance in the injection wells particularly in KN1RD. To ensure reduction or elimination of solids production from the primary suspect well KN3B, the liner break should be repaired. Monitoring of other production wells for solids production should also be implemented.

2.2 Drilling of additional re-injection Well KN2RD

Well KN2RD was drilled from June 25, 2002 to August 23, 2002 and obtained a depth of 2,263 meters. The well was intended to augment the injection capacity in Pad C and as replacement injection well for KN1RD during workover of the well. Geological and drilling parameters indicated five structures intersected. Two permeable zones were identified, a minor permeable zone at 1850-1900 meters and a major permeable zone beginning at 2100 down to bottom. The well exhibited poor permeability due to inherent tight fractures within the open hole section with only minimal drilling losses of 0.2 to 0.75 BPM encountered. Three hydro-fracturing attempts were undertaken but yielded no significant improvement in fluid acceptance. Calculated injectivity index is from 4.6 to 6.7 li/s-MPa after the second and third hydro-fracturing jobs respectively. The estimated brine acceptance is < 10 kg/s.

The well was utilized for brine injection beginning January 2005 after KN1RD again showed declining injection capacity. The measured brine flow in February 2, 2005 was 18 kg/s. Subsequent measurement in the well showed a further improvement in brine acceptance to a maximum of 23 kg/s measured in January 2006. Despite two re-injection wells utilized for Pad C brine disposal, dumping remains a threat as KN1RD injection capacity goes down to zero with time and the minimal capacity of KN2RD cannot fully contain the total brine flow.

2.3 Installation of two-phase branch line solids strainer in KN5D

The decline in acceptance of well KN1RD was mainly a result of solids production from other M2 production wells. Well KN5D is one of the wells suspected of contributing solids. The well discharges highly two-phase fluids at minimal water flow to nearly nil. The well was put online in September 2000 immediately after well completion without going through a medium-term discharge test. The well was cut-out after KN1RD went online in June 2002. The well had to undergo a repair of the wellhead. It was again utilized in March 2003.

Figure 5 shows the strainer installed along the two-phase line upstream of the separator stations in June 2003. The strainer was removed in October 10, 2005.

Figure 5. The two-phase strainer installed in a production well suspected of contributing solids. The strainer reduced the power output of the well by 1-2 MW and was subsequently removed.

Installation of a two-phase strainer in KN5D used about 2 kg/s of steam equivalent to 1 MW based on flow measurements. After nearly three and a half months of continuous utilization, no debris or solids were 'captured' by the strainer. Apparently, the solids produced by KN5D are finer and are believed to be effectively scrubbed at the separator stations. The purpose of the solids strainer is to scrub solids outright from the well before the two-phase fluids are mixed and to reduce solids carry over that is not scrubbed at the separator. The finer solids debris (< 1mm) produced by the well are partially captured in the solids trap but most are carried over into KN1RD. The design of the solids strainer needs improvements to efficiently capture the solids carry over. The removal of the strainer resulted in a minimal gain in output.

2.4 Solids trap reconfiguration / modifications

Solids entrained from the production wells of M2 results to debris being transported into the injection wells. This has proven to be a problem since the injection well capacity has been greatly reduced necessitating excess brine to be pumped from the site C sumps to pad RA. Ideally, the solids trap (ST) functions to capture these solids in the brine before it is injected back to the well. To improve efficiency of the solids trap the following measures were implemented:

- Relocation of pad C brine line ST from pad cellar to surface (July 2003).
- Installation of redundant RI line to KN1RD (Nov 2003).
- Installation of over-sized solids trap from 24"dia. to 30"dia. in the first quarter 2004 (and 20" dia. to 24" dia. in the redundant line)
- Monthly cleaning of the solids trap beginning May 2004 (both 30"-dia. and 24"-dia.).

Figure 6. The original location of Pad C MBL solids trap in a deep cellar. The trap was only 18" in diameter and produced a fluid flow that was not effective in capturing large amounts of solids.

The original location of the 24-inch diameter solids trap in pad C was at the pipe trench leading to well KN1RD (Figure 6). The solids trap was relocated to the surface upstream of the main brine line (Figure 7). The relocation was completed in July 2003. Initial inspection of the ST after four months of continuous utilization found more accumulation of solids debris compared to its original location at the pipe trench. However, the debris profile inside the pipe suggested two-phase flow or high velocity failing to efficiently capture more solids entrained in the brine. To address this occurrence a provisional solution was implemented where the 6-inch diameter level control valve (LCV) found downstream of the separators was replaced with an 8-inch diameter pipe spool. Inspection thereafter showed debris profile inside the ST with a "smoother, laminar" (lower velocity) flow being attained. Finer solids debris was observed to be captured by the solids trap. However, subsequent inspections indicated again two-phase flow conditions. To reduce fluid flow velocity and control occurrence of two-phase flow, the pipe size of the ST was increased from 24-inch to 30-inch diameter. This proved to be efficient based on the subsequent inspections where debris profile suggested fluid flow velocity has been significantly reduced thereby increasing solids capture.

Apart from the foregoing changes implemented, a redundant line was constructed parallel to the main brine line (MBL2) and installed with a 20-inch diameter ST (Figure 7). In the same manner as the main ST, the 20-inch diameter pipe was later replaced with the 24-inch diameter pipe installed previously in the MBL2. The redundant line was commissioned in November 2003. The redundant line is primarily utilized as a bypass brine line during inspection/clean out of the main brine line solids trap. On inspection of the redundant ST, debris profile almost always shows two-phase flow profile. The flow profile is likely a result of the design of the pipeline. Initially, the design called for a bifurcator installed at the upstream section of the brine line such that the STs would run parallel outright. The present design is that the pipeline of the redundant line is stubbed-in to the main brine line as shown in Figure 7. To improve the efficiency of both STs, the original design for the brine line should be implemented.

Figure 7. Above shows the location at pad surface of the two 30"-diameter solids trap modification from the original set-up. Adding a redundant solids trap allows cleaning of one solids trap at a time without affecting continuous brine injection.

Figure 8. Maintenance crews conduct regular monthly cleaning and inspection of the traps to maintain its efficiency.

The regular cleanout of solids trap began May 2004 (Figure 8). Figure 2 shows the trend of debris collected during inspection of the solids trap. As much as 1930 kg of debris was accumulated in the solids trap after the Mindanao-2 Power Plant shutdown in February 2005 (Figure 4). Correlation with the injection flow to KN1RD indicated a significant decline. Injection flow decreased to 30 kg/s although the well showed some recovery but not to its initial acceptance. The huge volume of debris apparently reduced the capacity of the STs. After nearly blocking the STs, solids carry over into KN1RD increased thus reducing its flow acceptance based on the tracer flow measurements conducted. The debris collected is characterized as 50-80% rock fragments, 15-40 % corrosion products and <10 % amorphous silica (Dulce, 2003). As mentioned earlier, debris removed from KN1RD in the 2004 workover is characterized as sand-sized fragments which are easily carried over from the ST. This is evident in the persistent decline in acceptance of well KN1RD.

An evaluation of the site C solids trap efficiency shows that finer particles require a longer pipe to completely capture all the particles entrained in the fluid. At a mass flow of ~75 kg/s, the minimum particle size that can still be carried for a certain distance is ~1.65 mm. The present length of 6 m inefficiently captures finer solids at < 1.65 mm which is carried into the injection well.

2.4 Brine pumping

Brine pumping has been resorted to since the onset of Mindanao-2 production. Brine pumping is necessitated once pad C sump has reached the critical capacity level or water level (WL). The net effect is temporary diversion of excess brine injection to KL2RD to reduce brine overflow from the pad C sump otherwise Mindanao-2 will have to reduce its load to contain the excess brine flow due to environmental constraints.

Since the onset of M2 production, load reductions of at least 1-2 times per year have occurred as a result of KN1RD injection capacity decline. These load reductions persists in 6-8 hours duration which translates to a huge energy generation loss. Furthermore, frequent breakdowns and high fuel consumption of brine pumping results to high costs for this measure.

3. PROBLEM ANALYSES AND SOLUTION

After a series of technical meeting and drawn-out discussions the following facts have been established in KN1RD:

-solid debris is constantly accumulating at Pad C MBL at a rate of 5 kg/day.

-Solid debris is mostly rock fragments consisting of 50-80% rock fragments, 15-40 % corrosion products and <10 % amorphous silica

-blockages were tagged by downhole survey tools inside KN1RD prior to workover.

-Maximum clear depth (MCD) of KN1RD after workover is variable indicating left-over debris.

-Persistent appearance of diorite found only in KN3B in the solids trap debris

This information formed the basis for the strategy to address the recurring injection capacity decline in KN1RD. The first involves stopping or minimizing the input of solids from the source which is KN3B as inferred from available data and optimizing the clean-out of accumulated debris in KN1RD by applying the right workover procedure.

3.1 Workover and Re-lining of KN3B

Workover of KN3B was undertaken beginning April 29, 2006 and was completed June 13, 2006. Completion tests indicated an injectivity index of 37 -38 li/s-MPa which is a significant improvement from the post drilling injectivity index of 18.7 – 21 li/s-MPa. Well KN3B was recommended for workover to repair the obstruction found at 18 meters within the 13-⅜" casing and the suspected damage within the 9-⅝" liner at approximately 2500-2650 meters. The former obstruction at 18 meters was tagged by an 8-½" diameter go-devil (GD) tool during a downhole survey in 1999. No attempts to repair were undertaken since then as the output of the well was found to be unaffected by the obstruction. Based on the evaluation the damage may have already occurred since 1994. Expansion of the trapped fluids between the 13-⅜" and 18-⅝" casings due to increase in temperature may have exceeded the collapse strength of the 13-⅜" casing, which resulted in casing collapse/ break.

Well KN3B was identified as the major contributor of solids based the rock fragments collected from the solids trap. Based on petrologic analysis, these rock fragments consisted mostly of diorites, monzodiorite, microdiorite, dacite and andesite and only KN3B intersected diorites at depths 2500 –2650m. Moreover, remains of corroded metal were collected in Mindanao 2 FCRS in November 2002. These fragments of corroded metal resembled part of a damaged 9-⅝" liner where casing threads similar to a 9-⅝" perforated liner were visible. Only KN3B has a 9-⅝" liner hooked-up on the Mindanao 2 FCRS.

The workover required a downhole viewer (DHV) to be run to visually ascertain the particular casing and liner failures and to be able to carry out the appropriate strategy in repairing the damage. The 13-⅜" casing clearing operations began on April 30, 2006 initially tagging the obstruction at 20.2 meters. The obstruction was milled to enable the 8-½" bit assembly to penetrate further downhole. Other sections were also milled within the 13-⅜" casing. Within the 9-⅝" liner, an obstruction was tagged at 1562 meters,. At this stage, a pressure build up test and KT survey were conducted prior to the downhole viewer (DHV) survey. The DHV survey was ran downhole on May 9-10, 2006. Figure 9 shows the parted 9-⅝" perforated liner at 1565.53 meters with an open hole gap of approximately 2.5 m. The open hole gap is where the solids enter the borehole.

Pressure-temperature-spinner survey was conducted after the DHV survey on May 16, 2006 to establish other inflow or loss zones within the 13-⅜" casing and seal with cement plugging. The stationary runs were done while pumping water at 12.2 BPM through the annulus. Downhole pressure profile while pumping water revealed the water level at 496 meters and without pumping at 770 m. Based on the temperature profile the most likely exit points are 27.8 meters, just above depths 600, 1000 and 1210. Except for depth 1000 m, the suspected exit points correlate with the breaks found at 27.8, 577.5 and 1195-1198 m. The isothermal-like profile noted from 600 – 775 m implies inflow of hot fluid. Fluid velocity at the points where spinner was set was not high enough to generate spinner rotation.

Subsequent downhole temperature surveys (May 28 and 29) after setting a bridge plug at 921 m and cement plug at 883 m, show the other suspected loss zones at the following depth intervals (in meters): 25 – 50, 259 – 309, 359 – 409, 434 – 509, 534 – 684 and 734 – 784. These zones were recommended to be cement plugged prior to relining the 13-⅜" casing. Pressure tests however established a significant leak between 534 – 684 m. Cement plugging was conducted thereafter and pressure tests indicated successful sealing of loss zones.

Relining of the 13-⅜" casing was done in two stages: from 922 – 1234 meters, with 9-⅝" perforated liners and 9-⅝" casing from to 881 meters. The 9-⅝" perforated liners were set to leave open the suspected feedzone at 1000 and 1210 meters, as established by PATS. The 9-⅝" production liners were relined with a 7" perforated liner squatted at 1565 meters, just about the parted 9-⅝" liner at 1571 meters,. The total length of 7" perforated liner is 355.5 m which sets the new top of liner at 1210 meters.

The two relining operations address the entrainment of solids into the wellbore and the reduction in output of the well as a result of the smaller casings used for repair (Daco-ag, 2007).

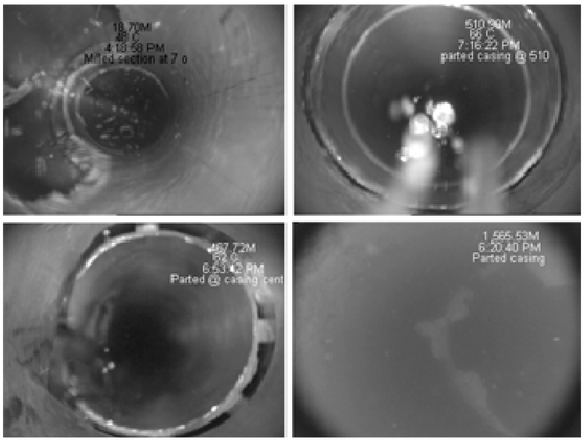

Figure 9. These are down hole viewer (DHV) images showing the casing and liner damage in well KN3B. The large cavity from the parted liner is a likely source of the large volume of solid debris. The types of rock encountered during drilling at the location of the liner damage are similar to those collected from the solids traps.

3.2 KN1RD Workover using Venturi Jet

Quenching of the well KN1RD for workover commenced on February 24, 2008. Prior to running in of the clearing assembly a 4" Go-Devil tool was run-in and tagged a blockage at 1019 meters. Mechanical clearing of KN1RD with rig was able to penetrate the length of the 9-5/8" production casing using 8-1/2" bit from CHF down to top of liner at 1011 meters without any obstruction encountered. After clearing down to top of liner (TOL), a 6" bit was run-in to clear the 7-5/8" slotted liner and tagged obstruction the main obstruction (suspected to be the fill) at 2169.2 meters about 24.4 meters short of the post drilling bottom of liner depth of 2193.6 meters.

The rig attempted to drill out the obstruction but experienced high torque and over pull (Javier, 2005). As planned, a venturi jet with 5-3/4" core type junk basket assembly was run-in and tagged the obstruction. The venturi assembly was able to recover fills composed of sandy materials composed of rock debris consistent with those recovered from the MBL solids traps. A further three washing of liner passes were conducted by the rig before the workover was completed.

Because the workover / venturi jet was largely unable to extract a large volume of the solids debris at the bottom of KN1RD, a sustained discharge of the well was programmed to eject the fill. The well was heat-up for 35 days and discharged on April 18, 2008. The well sustained discharge for five days and afterwards shut for subsequent use of the well for injection. Dumping immediately ceased after cut-in of KN1RD indicating full acceptance of brine.

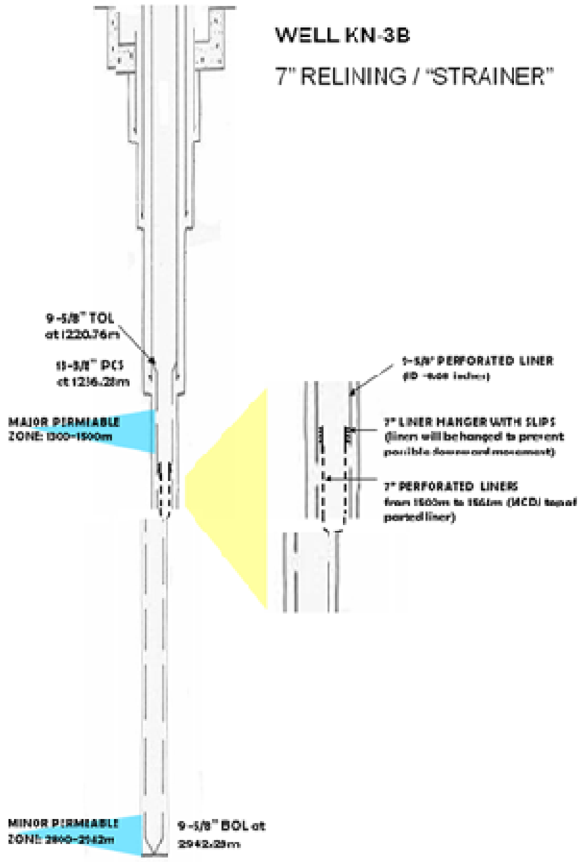

Figure 10. To minimize the amount of solids coming from the liner break, a "strainer" consisting of liner hanger with slips is inserted into the break. The size of the rocks collected from the traps after the installation of the strainer has been reduced to sand size.

Figure 11. The venturi jet assembly was used during the last workover in KN1RD to remove the solids fill at the bottom of the well which cannot be circulated out by the rig.

Figure 12. Sand sized rocks collected by the venturi jet from KN1RD. Although the tool was successful in capturing a large amount of solids, the limited volume of the tool requires multiple run-ins which were considered impractical.

4. CONCLUSION

The measures done at the FCRS to minimize if not eliminate solids in the system achieved only partial and temporary successes mainly because these did not address the root problem, which is the source of the solid materials in the discharge.

Identifying the root cause of the problem was difficult due to the unavailability of critical information such as where the solids were coming from, the amount of solids being produced, the efficiency of the traps in preventing solids carry-over to the re-injection wells and how the accumulation of debris influence the injection capacity of the well. The information came about mainly as a result of trial and error and field experiences gained through time. Other hypothetical causes such as wellbore silica scaling and reservoir permeability limitations were pursued initially and which caused a delay in isolating the root of the problem.

Although the problem has been clearly identified, technical difficulties were encountered in implementing the solutions. First, a system must be developed that could eliminate solid particles (sand and silt-sized) in the in the discharge without seriously affecting the output of the well. Installation of a two-phase strainer in KN5D produced an estimated 1 MW in the output of the well. The wellbore intervention in KN3B likewise reduced the power output of the well by about 1 MW. Secondly, effective cleaning of re-injection wells with accumulated solid debris at the bottom is hampered by current techniques. The use of venturi jet achieved only partial success in retrieving the solids. It was only after an extended discharge of KN1RD, that full brine acceptance has been achieved.

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