Integrated Services Achieves Multi-String Casing Exit and Re-Drill in Geothermal Well

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ABSTRACT

Puna Geothermal Venture
Well Name: Kapoho State-11RD (Geothermal Well)

Tests and surveys on the Kapoho State-11RD, a geothermal well near Hilo on the island of Hawaii, indicated a shallow leak into the formation zone. Injection fluid was traveling through the current fractures from the re-drill to the original wellbore, creating interference problems with the production zone of another well. Re-drilling was considered, but the decision was made difficult by previous re-drilling and workovers to the well, and the proximity of any new bore to the previous bores.

A coordinated research effort involving Baker Hughes Integrated Services and the client, Ormat, revealed that the most economical procedure would be to relocate the target and kick-off point, sidetrack the well by performing a casing exit through the two casing strings to increase the separation from any previous wellbores, and then directional drill the hole to the designated target.

A window was milled in 37½ hrs, including drilling 15 ft of formation below an extra long whipstock ramp that was more than 19 ft long. The PDC mills cutting structure allowed milling with lighter weight, which enabled the mill to stay on the face of the whipstock and avoid departing from the ramp prematurely.

Even though the T-95 and T-90 casing grades usually require several runs to mill a window through two strings, and drilling with a PDC formation window mill is also difficult, the window was successfully milled. When running the drilling bottomhole assembly (BHA) through the window, no drag was encountered. The 7-in. casing was also run through without drag and then cemented.

The 5⅞-in. productive interval was drilled 120 ft when it was discovered that the 7-in. liner cement job was fatally flawed, and this entire interval was abandoned.

A second window was milled several hundred feet above the first, through the same two strings of casing, using the same equipment and methods. This window was similarly successfully milled in 30½ hrs. The 8½-in. hole was drilled, and the 7-in. liner was run and cemented. The 6¼-in. productive interval of this sidetrack was successful in encountering the top of production at 5,135 ft and was drilled to 6,872 ft, where pipe was inadvertently stuck in the hole. It was completed with 4.5-in. pre-perforated liner from 4,755 to 4,755 ft and a combination 7-in. and 5-in. alloy injection hang down string from surface to 3,038 ft.

Job success was attributed to a team effort involving Ormat, Geothermal Resources Group and Baker Hughes Integrated Services. Coordination included the engineering, technical advice and field support services to achieve this task. This paper describes the well condition, the project plan, the equipment/materials used, and the procedure.

Casing Exit Technology Overview

Prior to the progression of wellbore intervention technology, specifically at the advent of casing exit technology, improper trajectory of a cased wellbore into a reservoir necessitated that another well be spudded to potentially reach the intended production interval. The ability to exit a well's main bore casing came from the need to reach a desired reservoir zone without drilling an additional main bore and well.

The primary methods of creating an exit in casing include section milling and window milling. As the name suggests, section milling involves milling away the complete circumference of a length of wellbore casing or liner at a predetermined well depth. The section milling method of exiting casing can be completed using available equipment such as section mills.

In a geothermal well, however, the formation behind the casing is usually abrasive, and when using a section mill, the carbide milling arms are prematurely depleted and require several runs to mill the window. Section milling through two strings of casing would require several runs and be very costly. The additional contact of the drillpipe tool joints against the casing while milling can cause excessive wear to the casing above the window. An advantage of the window milling method over the section milling method is that less cutting debris material must be circulated out of the well during the window milling.

Well Background Information

The Kapoho State-11RD well, a geothermal well near Hilo on the island of Hawaii, previously underwent a re-drill and several workovers. (Figure 1 shows a schematic of this well after a May 2004 workover.) The original 11¾-in. casing in was set at a depth of 5,061 ft. It was plugged back with 195 ft^3 of cement at 4,652 ft, and a window was milled from 4,367 to 4,422 ft. This enabled an initial re-drill, with a 10⅝-in. hole that was drilled to 7,950 ft.

An obstruction in the well necessitated that this well be re-plugged, this time back to a depth of 6,430 ft. An 8⅝-in. slotted liner was hung from 4,192 ft to a depth of 6,405 ft, and then a 9⅝-in. liner was cemented from the surface to 3,200 ft, to seal off holes in the 11¾-in. casing. During a workover in 2006, a 6⅝-in. liner was cemented with latex cement from 4,028 to 4,752 ft.

Another re-drilling of the KS11RD well was considered because injection fluid was traveling through the original well and interfering with the production zone of the nearby KS-5 well. A spinner survey performed in 2006 indicated that most of the injection fluid was entering the formation zone at 5,000 ft. Results from a nitrogen purge test in April 2008 revealed that the shallowest wellbore leak was at 4,835 ft.

Casing Exit and Re-Drill Plan

The re-drill plan would begin by plugging the productive interval with cuttings and clay. Cement plugs would be used to abandon the wellbore, and then a whipstock would be set on top of the cement. A window would be milled through two strings of casing, 9⅝-in. 47 lb/ft T-95 casing and 11¾-in. 65 lb/ft C-90 casing. The well would be re-drilled with an 8½-in. bit to 5,000 ft and then 7-in. casing cemented in place to seal off any possible leakage to the old wellbores before drilling the productive interval.

There was some risk that a re-drill of KS11RD would result in unwanted fluid flow from KS-11RD into the production of KS-5. However, this risk could be minimized by plugging the current wellbore and re-drilling KS-11RD from a point over 1,000 ft in vertical distance from the shoe and to the northeast, to a new target in the KS-5 production interval.

The most economical procedure was to relocate the target and sidetrack the well at 3,200 ft to minimize doglegs while directional drilling the hole to the designated target and increasing the wellbore separation in the productive interval. Performing a casing exit at this depth would save the customer the cost of preparing a new surface location well pad, pipelines to the plant, and wellhead equipment. The associated costs of drilling three hole intervals and three strings of casing and cementing also had to be considered.

The directional services team planned a well path map from the casing exit to the new target. The exit depth was determined to be 3,200 ft. At this location, the well had 9⅝-in. 54 lb/ft T-95 casing cemented inside 11¾-in. 65 lb/ft T-95 casing. This plan required using a whipstock oriented to the desired target (to avoid any casing couplers) and milling a window through both casing strings. (See Figure 5 for an exemplary test fixture used during a casing exit test of the improved casing exit milling system.)

Motor and Bit Details

For the 8½-in. hole section, a 6¾-in. medium-speed extra-high torque high-performance downhole motor was selected. This motor had a 5/6 lobe power section, .33 rev/gal ratio and 5,050 ft-lb of torque. The bit selected was an IADC Code 517. (Reference Table 1.) This bit had single energizer metal seal to provide long life in a high-RPM motor application. It was also equipped with extra stabilization and enhanced OD protection. The objective goal was to drill each respective hole section (8½-in. and 6½-in.) with one selected motor and drill bit.

The objectives were accomplished by meeting the directional needs and completing this 1,836-ft section with one motor and one bit. The run took 63.5 hrs with a 29.61 ROP. The IADC code 517 bit accumulated 892K revolutions on the bearing, which included drilling, reaming and hole cleaning.

For the 5⅞-in. and 6¼-in. hole section, a medium-speed extra high torque 4¾-in. motor was again selected with a 5/6 lobe power section, 1.03 rev/gal ratio and 2,600 ft-lb of torque. The 5⅞-in. bit was an IADC Code 447, and 6¼-in. bit was an IADC Code 477. These bits had single energizer metal seals to support the high-RPM motor application. They were also equipped with enhanced leg protection.

Again the hole section objectives were met, drilling 1,990 ft in 63 hrs for a 31.7 ROP. The IADC Code 447 bit also accumulated 889K revolutions. Due to hole problems, this bit was lost in hole and never recovered. For this reason, its dull grade was not rated.

The KS-11RD3 was directionally drilled from an oriented whipstock. The whipstock was set and the milling BHA milled through a dual 9⅝-in. and 11¾-in. casing string. The 8½-in. directional hole was drilled to a depth of 4,909 ft. This re-drill was completed in a 6¼-in. hole to a total depth of 6,872 ft. The objective goals were met, drilling each hole section (8½-in. and 6½-in.) with one selected motor and drill bit.

Table 1. KS-11RD3 Puna Geothermal Ventures Parameters.

IADC	Size (in.)	Motor RPM	Rotary RPM	Total RPM	Footage	Motor Bend (°)	GPM	WOB (Klb)	ROP (ft/hr)	Hrs	K-Revs	Slide %	Rotate %	Dull Grade
517	8½ *	197	30	227	1836	1.3	597	30	29.61	62	892	35	65	3, 3, WT, A, E, I, NO, HP
447	6¼ ^	212	30	242	1999	1.5	206	13	31.73	63	889	13	87	Lost In Hole

Data aquired from Bit records and INTEQ DDRs.

* 8½ IADC 517 bit also used for reaming and cleaning the hole section for a total additional 24 hrs. This is reflected in total K-Revs (1000 revolutions).

^ 6¼ IADC 447 bit has no dull grade because the bit was lost In hole.

Drilling Fluid Details

The drilling fluid system used on the Puna KS-11RD2 and the 11RD3 was a bentonite/xanthan gum mud system. This system was comprised of Wyoming bentonite, a complex polysaccharide and xanthan gum. The complex polysaccharide (BPac) used in conjunction with Wyoming bentonite and xanthan gum provided improved shear thinning characteristics. The API fluid loss was further controlled with a vinyl sulfonated copolymer (AMPS/AM). Micronized cellulose (Microcell) was used as the primary lost circulation material (LCM). The LCM concentrations in the mud system ranged from 2% up to 5% by volume, depending on the severity of mud losses. Additional microcell was used for sweeps to improve hole cleaning and to control seepage. The approximate formulation and fluid properties of the bentonite/xanthan gum mud system are shown in Tables 2 and 3.

Table 2. Formulation of Bentonite/Xanthan Gum Mud System.

Product	Description	Function	Concentration (lb / bbl)
Gel	Bentonite	Viscosity and fluid loss control	10 to 17.5
BPac	Complex polysaccharide	Low shear rate viscosity and fluid loss control	0.4 to 0.75
Xanthan Gum	Biopolymer	Low shear rate viscosity	0.3 to 0.5
(AMPS/AM)	Vinyl sulfonated copolymer	Viscosity and solids suspension	0.3 to 0.5
(Microcell)	Micronized cellulose	Lost circulation and in sweeps for improved hole cleaning	2% up to 5% by volume

Table 3. Fluid Properties of Bentonite/Xanthan Gum Mud System.

Fluid Property (Active Mud System)	Range
Density, lb/gal	8.5 to 8.9
Funnel Viscosity, sec/qt	40 to 44
Plastic Viscosity, cP	8 to 14
Yield Point, lbf/100 ft^2	9 to 12
10 sec Gel Strength, lbf/100 ft^2	3 to 4
10 min Gel Strength, lbf/100 ft^2	5 to 7
API Filtrate, ml/30 min.	10 to 19
pH	7.5 to 9.0 (max of 11.5 from cement)
MBT, lb/bbl Bentonitic Equivalent	10 to 15

The well was drilled 4,745 ft and a drilling liner was run cemented. Then it was drilled to the standoff from the lease line without encountering any significant production zones. The well was plugged back again to just above the window and sidetracked through a second window that was milled as successfully as the first. A drilling liner was run and cemented from 2,824 to 4,873 ft.

When the target zone was reached on the KS-11RD3 well, a total loss of circulation occurred. Thereafter, water was used as the drilling fluid. The remaining mud was isolated on surface, conditioned with microcell, and used for sweeps to assist with hole cleaning and suspension of drilled cuttings. A sweep of approximately 20 bbl was pumped for every 15 ft of hole drilled, and more frequently when necessary. The water was fed directly into the pill tank and used for drilling. Partially-hydrolyzed polyacrylamide (PHPA) was added to the water to improve lubricity.

Casing Exit and Re-Drill Plan

Mobilization and rig-up occurred on October 26, 2009 and BOPE was nippled up on KS-11. The 22CR alloy hang down injection liner was pulled and laid down. Clean-out occurred through the 9⅝-in. and 11¾-in. casing and to 4,863 ft inside of the 8⅝-in. liner. The wellbore was plugged with sand and cement plugs, and then abandoned. The cement was cleaned out to 3,194 ft, and then the casing was pressure-tested above the plug.

The whipstock was oriented and the anchor was set on the cement with the top of the ramp at 3,169 ft. In one trip, the window was successfully milled through the 9⅝-in. 47 lb/ft T-95 casing and the 11¾-in. 65 lb/ft C-90 casing from 3,169 to 3,206 ft. To extend the window, a second trip was made with a stiff milling assembly. The whole operation took 37.5 hrs to complete. Then an 8½-in. hole was drilled with three LC plugs to 4,745 ft and a 7-in. drilling liner was run and cemented from 4,741 to 3,126 ft. No issues were encountered with the window or whipstock. A 5⅞-in. hole was drilled only 120 ft out of the casing shoe, where significant losses were encountered, indicating that the liner cement job was not successful in isolating this

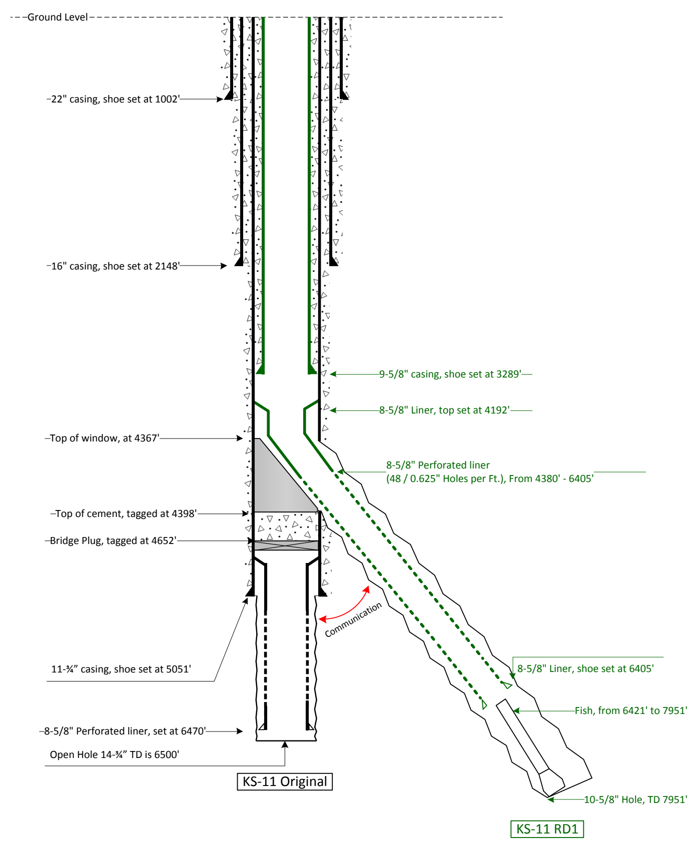

Figure 1. Schematic of KS-11 well completion after May 2004 workover.

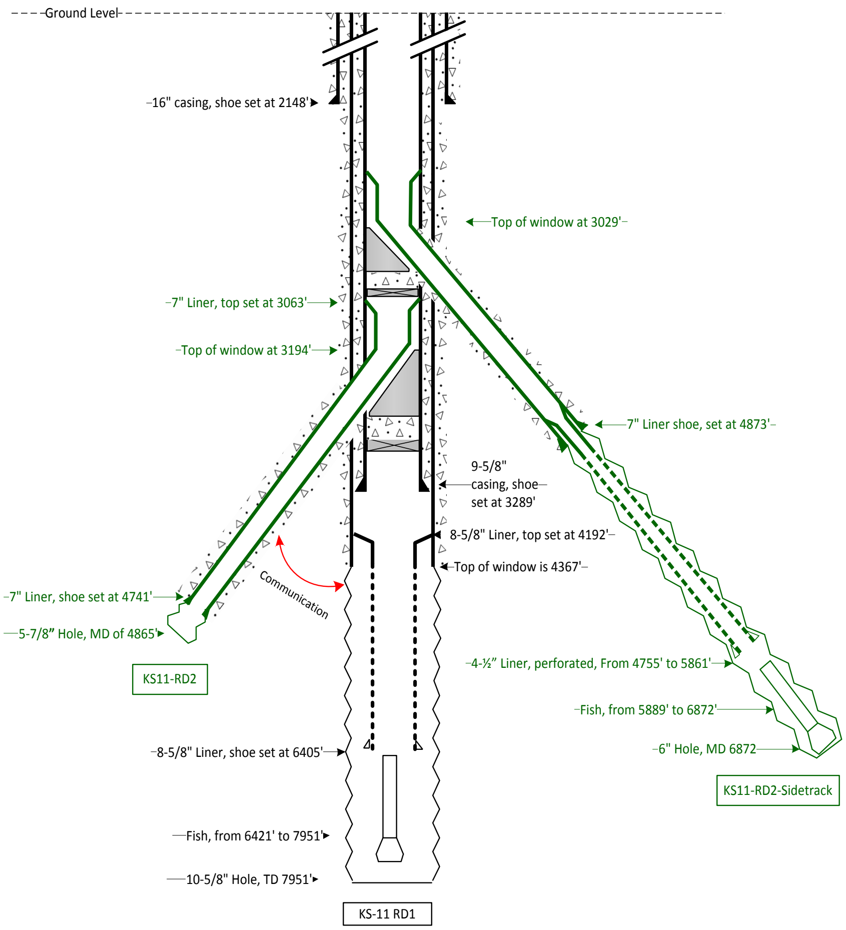

Figure 2. Schematic of KS-11 well as of December 2009, after two dual-string casing exits.

wellbore from the previous wellbore, which was the primary intent of the re-drill.

This wellbore was plugged back and abandoned with cement to above the top of the window. A second whipstock was oriented and set on cement at 3,031 ft with the top of the ramp at 3,029 ft. Again, the window was successfully milled in one trip through the 9⅝-in. 47 lb/ft T-95 casing and 11¾-in. 65 lb/ft C-90 casing from 3,031 ft to 3,073 ft. The window was again extended with a stiff milling assembly. The whole operation took 30.5 hrs to complete. Then an 8½-in. hole was drilled to the northeast with 5 LC cement plugs and a 7-in. drilling liner was run and cemented from 4,873 to 2,824 ft. The 6¼-in. hole was drilled to the first major loss zone (4,909 ft) with mud, and then, to keep the hole clean, it was drilled blind with sweeps to 5,135 ft. The drilling assembly became stuck at that point and was eventually abandoned in place.

A 4½-in. pre-perforated liner was run and set from 5,861 to 4,755 ft and a combination 5-in. 22CR and 7-in. 22CR & 25 CR hang down injection liner was run and hung from surface to 3,038 ft. Again, the hole was drilled with no issues encountered with the window or whipstock. The BOPE was nippled down and the rig moved off on December 17, 2009. Therefore, two sidetracks were drilled and the well successfully re-completed for production in less than two months. The normal time to complete a "grass-roots" well is three months. Significant savings were realized.

Casing Exit Equipment and Materials

- Whipstock anchor
- Whipstock
- 8½-in. PDC formation window mill
- 8½-in. (special design) lower watermelon mill
- 8½-in. flat bottom mill

BHAs

BHA 1

Figure 3. Exemplary used PathMAKER PDC formation window mills.

- 9⅝-in. anchor
- 9⅝-in. whipstock with a ramp of 19.7 ft
- 8½-in. PDC formation window mill (Reference Figure 3.)
- 8½-in. lower watermelon mill dressed with special carbide
- UBHO NC50 box
- HWDP NC50 box
- X-O 4½ XH box

Reamed out window and made three passes - no drag, window good, tripped out for drilling BHA. (1 hr reaming time)

BHA 2

- Mill 4½ Reg
- X-O 4½ XH box
- X-O NC50 box
- Lower watermelon mill NC50
- Upper watermelon mill NC50
- X-O 4½ XH box
- DC (6) 4½ XH box S/No: RIG
- X-O (1) NC50 box S/No: RIG
- Jars NC50 box
- HWDP NC50 box

Results

The windows were milled in 37½ hrs and 30½ hrs, respectively, including drilling into hard rock formation significantly below the extra-long whipstock ramp that was 19.7 ft long. The mill cutting structure and design yielded enhanced ROP with lighter drill weight than normally required to keep the mills on ramp to avoid premature mill ramp departure. The casing was T-95 and C-90 grade, which is typically very difficult to mill. It usually takes several runs to mill a window through two strings of lower-strength casing, and the formation is very difficult to drill with a mill. The 8½-in. holes were drilled successfully with no drag when running the drilling BHA through the window. The 7-in.liners were run with no problems or excess drag through the windows.

Conclusion

Job success was attributed to a team effort. Ormat, Geothermal Resource Group and Baker Hughes (Integrated Services) worked as a team, contributing engineering, technical advice and field support services to achieve this task.

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Baker Hughes provided drilling fluids, drill bits, directional and window cutting services.

Window Cutting System

The one-trip window cutting system, with the carbide window mill or PDC formation window mill, provides a means to efficiently exit casing and provides a window through which it is suitable to run a drilling BHA, liners, and completion equipment. The complete window is normally accomplished in one round-trip with drillpipe. In one trip, the starting cut is made, the window milled, and a pilot hole is drilled for the subsequent drilling. (Ref Fig 4.)

Retrievable Bottom Set Anchor

The retrievable bottom set anchor is used to anchor a whipstock in place in the wellbore. (Reference Figure 4.)

PDC Formation Window Mill

- PDCs capable of milling steel and formation
- Engineered by the world leaders in casing exits and drill bits
- Cuts hard formation casing exits in one trip
- Mills window and drills an extended rathole in one trip
- Allows directional drilling to begin immediately after casing exit
- Balanced spiral set cutter arrangement for smoother, cleaner cuts
- High set carbide cutters protect PDCs while starting the exit
- Aggressive all cutter center design allows for maximum penetration rates in formation
- Watercourses guide drilling fluid flow to efficiently cool and clean cutter elements

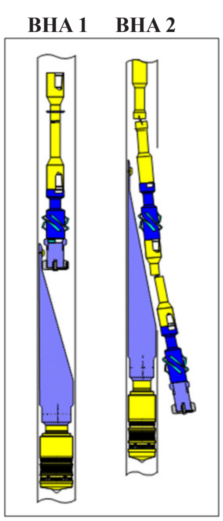

Figure 4. Milling BHAs, whipstocks, and anchors.

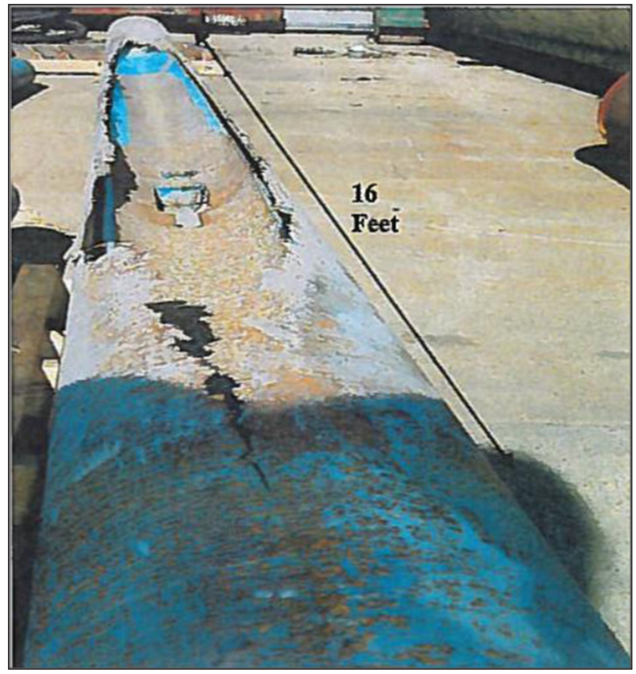

Figure 5. Exemplary test fixture used during casing exit test of the improved casing exit milling system.

Improved Casing Exit Milling System Design

When performing a casing exit, the technology includes toolstrings comprised of mills with cutting structures for traversing anchored whipstocks to create elliptically shaped windows. Successful casing exit operations involve generating windows sufficiently long for easy passage of subsequently run directional drilling BHAs and creating full-gauge ratholes that deviate from the exited casing and allow passage of the casing liner through the window for completion of the well. Maintaining sufficient restraining forces on the bottom-most mill is important to keep it tracking on the face of the whipstock for the full length of the ramp. Proper restraining forces prevent an early whipstock ramp departure and help generate a long window.

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