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A CASE HISTORY
THE COMPLETION OF A SHALLOW, OVER-PRESSURED GEOTHERMAL WELL

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ABSTRACT

This paper presents a case history of the drilling and completion of a shallow over-pressured geothermal well, Utah State 72-16, situated in the Roosevelt Geothermal Field, Beaver County, Utah. The problems encountered and the techniques used in completing this well are reported to assist other operators in safely drilling and completing in such shallow, over-pressured resources. The tasks of greatest difficulty were 1) the running of the 9-5/8" production casing and 2) remedying the consequence of an indicated imperfect cementing of the 13-3/8" surface casing. Patience, cooling of the well, and carefully performed and evaluated cement jobs were the techniques employed which contributed to the successful completion of these tasks.

This paper presents a case history of the drilling and completion of a shallow over-pressured geothermal well, Utah State 72-16, situated in the Roosevelt Geothermal Field, Beaver County, Utah. The problems encountered and the techniques used in completing this well are reported to assist other operators in safely drilling and completing in such shallow, over-pressured resources. The tasks of greatest difficulty were 1) the running of the 9-5/8" production casing and 2) remedying the consequence of an indicated imperfect cementing of the 13-3/8" surface casing.

Utah State 72-16 was spudded October 22, 1976 in Section 16 of the Roosevelt Geothermal Field\ by Thermal Power Company, Operator for a joint account with O'Brien Resources Corporation. A 12¼" hole was drilled to 85 feet in coarse granite alluvium, and then opened to 26". Conductor casing of 20" diameter was cemented at 85 feet with 200 sacks of cement. A 20" Hydril blowout preventer (BOP) was flanged to the conductor and a 17½" bit was used to drill below the shoe of the 20" casing. Drilling penetrated unconsolidated gravel, granite fragments and a pebble conglomerate of silicified granite fragments, when at 312 feet the well began to flow. The Hydril was used to shut-in the well, which registered 25 psig surface pressure. Drilling proceeded past 312 feet with mud weighted to 13.5 pounds per gallon (ppg). An alluvium/granite interface at 425 feet was drilled without incident, but during a deviation survey at 514 feet, the well flowed again. Drilling was continued down to 585 feet using 14.5 ppg mud, although mud returns were reduced or cut to 13.6 ppg and heated as high as 186°F. It was decided to weight the mud to 15.2 ppg, run casing, and cement the hot, mud-cutting zones behind pipe.

The 13-3/8" surface casing was cemented at 580 feet with 400 sacks of cement with good returns to surface by 2345 hours on November 1, 1976. Within 3½ hours the annulus between the 20" and 13-3/8" casing commenced flowing water, which was stopped with the Hydril. Before the annulus could be cemented from the top, a new seep developed outside the 20" casing in the cellar bottom. Finally, cement was applied both down the annulus and in the cellar bottom and a cement bond log (CBL) and temperature log were run.

There are two (2) components of a cement bond log; the amplified casing bond portion (CB), and the variable density log (VDL). Both portions must be interpreted for a correct determination of the cement bond. Reading the CB portion of the log of the 13-3/8" surface casing alone, the bond could be interpreted as being excellent from surface to 100 feet, fair from 100 feet to 260 feet, and excellent below 260 feet. Interpreting the two (2) logs together, however, reveals that from 0 feet to 22 feet there is only a fair bond, from 22 feet to 270 feet a very poor bond, and from 270 feet to bottom a poor bond consisting of a cement sheath resting (not bonding) against the formation. This latter phenomenon is revealed by the poor acoustical arrivals in the VDL log. Such arrivals are termed poor when the vertical lines of the VDL are relatively undisturbed. In the log of the 13-3/8" surface casing, only the sharp, evenly spaced signature of the casing collars is present, indicating that the cement sheath was incompletely bonded to the formation. Perforating and squeeze cementing behind the casing was not employed in these circumstances for several practical reasons. Drilling proceeded below the 13-3/8" surface casing with a readiness to make an immediate abandonment of the well if further adverse circumstances required it.

While drilling ahead with heavily salted water, the well kicked gas and some steam at 633 feet. After killing the well with 14.1 ppg mud, it was decided that further drilling would utilize mud to control the well's pressure. However, use of drilling mud had its own drawbacks because the high heat throughout the well caused the coagulation of barite and gel, making it very difficult to resume mud circulation after any interruption of drilling. Furthermore, the 14.1 ppg mud was constantly being cut in weight by additional heat and geothermal fluid entry. It was finally found that a mud weight of 15.2 ppg was required to prevent fluid entry and reduction of mud weight.

While weighting up the mud at 633 feet, the well was tested to determine if the well was sufficiently productive to merit completion. Testing was performed through the drilling stack and choke manifold, using the method of James. This technique was successfully employed at both 633 and 836 feet and proved insufficient productivity to complete the well at such depths.

On November 15, 1976, while drilling at 1245 feet, the drilling string torqued up and then spun free, accompanied by a loss of mud circulation. Some 300 barrels of lost circulation material (LCM), gel, and barite was pumped down with no returns. While building up a new supply of mud, the well was tested, and the readings of pressure and temperature indicated that a major hot water and steam flow had been encountered; the well was ready for completion. However, completion operations against the wellhead's pressure of 250 psig over hydrostatic presented tremendous problems. Even 15.2 ppg mud was being cut by the entry at 1245 feet, and the wellbore heat alone caused a significant decrease in density of mud statically resting in the wellbore. These problems with the mud, coupled with a reluctance to temporarily close a potentially productive zone with cement plugs, forced the used of "snubbing" equipment to remove the drilling string from the hole. This laborious operation alone required seven (7) days to set-up and perform.

The greatest problem threatening the safe completion of Utah State 72-16 however, was that of running the 9-5/8" production casing. Pressure control while running and cementing is important for a sound primary cement job. Even if a plug was set above the main zone at 1245 feet to isolate it, it was feared that the mud could be cut and heated by the upper zones, and a loss of pressure control occur. Additionally, should the casing be run successfully, the high temperatures at such shallow depths could cause the cement to flash set during its application, preventing a complete or satisfactory bond. Considerable time was devoted to analyzing these problems and their possible solution. However, on November 25, 1976, a stream of hot water and steam appeared approximately 25 feet southwest of the wellhead and commenced to flow steadily at about 15 gallons per minute. This event prompted the election to run and cement a string of production casing.

The effort to run 9-5/8" production casing commenced with the setting of a bridge plug at 1144 feet in the open-hole. The plug failed to seal off the pressure completely, as did a pill of 12% LCM dropped on it in an attempt to seal of possible leaks. Two (2) attempts were made to place a 75 lineal foot plug of cement on the plug; neither attempt succeeded. Despite these setbacks, however, much had been learned by now about how to deal with the well. Foremost of these lessons were the advantages gained by cooling the well with water before attempting operations with mud. The cooling promised savings of mud and rubber components of the BOP from the heat of the well. Accordingly, while mixing up heavy mud, the well was cooled by circulating water through open-ended drill pipe "hung" near the plug. When the 15.5 ppg mud was mixed, it was pumped into the well and displaced the water. The wellhead pressure was reduced to zero and remained safely so for several hours. This process of "cooling and killing" proved essential in the running and cementing of the 9-5/8" production casing.

On December 16, 1976 a slow (11 hour) process of washing and reaming wall cake down to the plug was started. Following this reaming, for 15½ hours the well was cooled by circulating water through the drill string, and up the annulus of the well. In rapid succession, the water was displaced with 16.3 ppg mud, the drilling string pulled out, and the rams of the Shaffer BOP's changed to handle casing. The 9-5/8" production casing string was modified to use the "cool and kill" method to provide a good cement job. The string sequence was a float shoe, one (1) joint of pipe, a float collar, a second joint of pipe with a centralizer, a "stab-in" float collar, a third joint of pipe with a centralizer, and the remaining 24 joints of casing. The casing was run in three (3) hours and the shoe set at 1098 feet below Kelly Bushing. Immediately, the mud was displaced and water again circulated through the hole, this time flowing down through the casing and shoe and up the annulus between the casing and the wall of the hole. This cooling continued ∿ 20 hours, then the water was displaced with 16.4 ppg mud, and mud was circulated outside the 9-5/8" production casing for ½ hour to condition the hole. Next, open ended drill pipe was run to the 'stab-in" float collar and 15.5 ppg cement slurry with 40% silica flour was pumped through the annulus between casing and open hole. Over 100% excess cement was used so that cement returns, although cut by water at first, finally had the same weight as that cement entering the well. It is believed that careful selection and control of cement slurry weight was of special importance in the circumstances at Utah State 72-16. Upon completion of cementing, the drill pipe was backed out of the "stab-in" collar, the mud displaced out of the casing, and cool water circulated in the casing to prevent the flashing of cement outside the 9-5/8" production casing. Three (3) float valves provided triple insurance that the heavier cement would stay in place and remain undisturbed while setting up. The circulation of the water up the annulus between the drill pipe and casing was a critical cooling operation which continued for 22 hours after the cement was emplaced. For a final time the well was killed with 15.0 ppg mud and an expansion spool and master valve flanged onto the production casing on December 20, 1976.

The effectiveness of this elaborate procedure on the 9-5/8" production casing was immediately investigated with a CBL. Bonding was fair to good from 20 feet to 86 feet, and excellent to very good from 80 feet to 548 feet. This region shows excellent cement bonding to the 13-3/8" surface casing as evinced by the strong "formation arrivals" in the VDL. From 548 feet to 1098 feet, the cement bonding is very good as shown by both the low amplitude of the CB and the continuous formation arrivals in the VDL. Some mico-annulus effect is shown by the moderate formation arrivals of the VDL (moderate meaning the first few arrival lines are generally undisturbed). However, a mico-annulus does not generally cause a loss of hydraulic seal. In short, the majority of the 9-5/8" production casing CBL is of a textbook quality.

Utah State 72-16 was cleaned out, deepened 9 more feet to a total depth of 1254 feet and completed with two (2) wellhead gate valves on December 31, 1976. Still to be corrected, however, were the consequences of the poor 13-3/8" surface casing cement job, manifested by the constant 15 gpm of geothermal water flowing from the seep near the wellhead. Considerable analysis again preceded action. On February 7, 1977, a grouting program for the well was initiated. Two initial vertical drill holes to 65 feet, located about 10 feet from the wellhead, failed to take sealant and stop the seep. Consequently, efforts were then re-directed towards sealing off the 13-3/8" surface casing cement sheath at the shoe of the 20" surface casing. An angle hole (G-3) directed towards this target successfully found the seep conduit, but grouting with Geoseal proved ineffective and the hole was plugged and abandoned. A fourth angle hole suffered the same fate, and was abandoned. A fifth angle hole (G-5) intercepted the seep's conduit again, so effectively that the entire seep's flow would exit G-5. Attempts to cement (instead of grout) the seep from G-5 only caused the cement to exit the seep and not setup. This led to the final hole, G-6, which also intercepted the seep's conduit. Cement was pumped through G-6 while G-5 was allowed to flow. Cement appeared in both G-5 and the seep using a 3/ to 1 mix of water and Portland Ideal, Type 1A cement. G-5 was gradually closed in while pumping down G-5 continued and the water-to-cement ratio was decreased markedly. As the slurry ratio was further decreased, pumping pressures began to build and the spring stopped flowing altogether. After two (2) hours of pumping a 0.75 to 1 slurry ratio at 70 psig, no further injection at that pressure was possible. This near classic "squeeze job", using 220 sacks of cement, stopped the seep and all gas flows in the well's cellar. The six (6) grout wells were capped and Utah State 72-16 was completed and ready for testing. On a 22-hour flow test in early April 1977, the well flowed from a reservoir of 468°F water at total mass flow rates up to approximately 1,300,000 pounds per hour. No surface seepages were found subsequent to this test. The well is presently shut-in awaiting further testing or production use. All wellbore data from Utah State 72-16 is now available to the public at the University of Utah Research Institute in Salt Lake City.

In conclusion, the history of Utah State 72-16 illustrates three (3) major requisites for dealing with a shallow, over-pressured well. First, such a well poses problems unique to the well and its geologic setting. Solutions to these problems are probably not obvious. Considerable thought, discussion, and experimentation is required for the discovery of these problems' solutions. Patience, then is the first requirement for completing such wells, even though such patience can be quite expensive. Secondly, cooling of a shallow, over-pressured geothermal well is a valuable tool in completing such wells. Keeping the well cool (1) saves the mud from heat and fluid entry degradation, (2) aids in a proper primary cement job, and (3) prolongs the life of such surface equipment as rotating head rubbers and BOP rams. In general, cooling the well buys the operator increased safety and greater operational flexibility. Finally, wells like Utah State 72-16 require a good primary cement job on each casing string. This involves careful attention to sufficient cooling and cement slurry weight and cement volumes to insure a good cement sheath. The follow-up of a good cement job should include a definitive appraisal of the job before proceeding with the well.

In summary, patience, cooling, and carefully performed and evaluated primary cement jobs, are recommended in any efforts to complete shallow, over-pressured geothermal wells.

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