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A SPECIAL APPLICATION COILED TUBING APPLIED PLUG FOR GEOTHERMAL WELL CASING REMEDIATION

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Abstract

Casing deformation in wells is a common problem in many geothermal fields. Casing remediation is necessary to keep wells in production and occasionally, to even enter the well for an approved plug and abandonment procedure. The costly alternative to casing remediation is to incur the expense of drilling a new well to maintain production or drilling a well to intersect a badly damaged well below the deformation for abandonment purposes. The U.S. Department of Energy and the Geothermal Drilling Organization sponsor research and development work at Sandia National Laboratories in an effort to reduce these remediation expenditures. Sandia, in cooperation with Halliburton Energy Services, has developed a low cost, commercially available, bridge-plug-type packer for use in geothermal well environments. This report documents the development and testing of this tool for use in casing remediation work.

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Introduction/Background

Geothermal wells are commonly drilled in harsh geological environments where geologic activity is prevalent. Steam and hot water production wells, in this environment, are exposed to recurrent geologic activity and this often results in formation shear or subsidence loads being applied to the well casings. Subsidence is generally the result of production where the reservoir fluids, water in this case, are not being adequately replaced and thus the formation may collapse and cause casing deformation. These progressive loads often cause the casing, at certain depths, to be deformed enough to reduce well production efficiency and/or restrict or prevent tool access to the well below the affected zones. If the casing is not satisfactorily maintained, the worsening deformations can lead to costly well repairs or result in premature plugging and abandonment of a producing well.

The Unocal Corporation, Division of Geothermal & Power Operations, installed and maintained geothermal production wells at The Geysers geothermal field near Santa Rosa, CA. These wells have since been purchased by Calpine Corporation. As a result of normal survey operations on these wells, over 50 of the 200+ wells in this field that belonged to Unocal, show indications of deformation in the well casings. At the request of Unocal, a two phase Geothermal Drilling Organization (GDO) proposal was prepared by Unocal and Sandia National Laboratories[1] to address casing remediation issues. As part of Phase I of this Geysers Deformed Casing Remediation proposal, Sandia was asked, by Unocal, to utilize the Drillable Straddle Packer[2] (DSP) design as a bridge plug for the casing remediation work. The DSP was developed by Sandia, as an inexpensive, high temperature packer for lost circulation treatment in geothermal wells. Although the DSP met the temperature and expansion requirements for this remediation project, some redesign and testing of the protective shroud, the bag packaging technique, and the deployment procedures would be required before the DSP could be used as a casing bridge plug.

A work schedule for this project was prepared by Unocal. Their schedule required a rapid response to Phase I of the GDO proposal, in order to meet time constraints, and left insufficient time for redesign of the DSP. Sandia recommended looking for a commercial packer that could be purchased off-the-shelf and used immediately or could be quickly modified to meet project requirements.

Technical Requirements and Product Search

Technical specifications for a Geysers casing remediation bridge plug were prepared by Sandia and Unocal and are as follows:

1. The well environment is steam.
2. The peak well temperature is 450° F.
3. The maximum well pressure is 200 psi.

4. The bridge plug will be deployed in a shut-in (no flow) well.
5. Prior to deployment, the plug must pass through a casing restriction with a minimum I.D. of 4.50".
6. The casing, where the plug will be deployed, is 11-3/4" (10.88" I.D. X .435" Wall), 54#/ft, Grade K-55 steel.
7. The plug must support 50' of dry sand followed by a 200' pour of cement.
8. The plug should be retrievable or drillable.

Based on these requirements, a search was initiated by Sandia for a suitable packer.

Unocal and Sandia contacted several inflatable packer manufactures in an effort to purchase an inflatable packer as a back up to the Sandia DSP. As stated previously the DSP was determined to be a long lead time item and an alternate packers were considered by the Sandia staff. Work experience in the oil field by Sandia personnel, prior to employment at Sandia, led to an investigation of the current status of the Gearhart-Owen Industries (GO) thru-tubing bridge plug. This plug could be set in small diameter casings on wireline, and could support sand and cement to form a casing plug similar to the plug needed for the casing remediation work. The GO bridge plugs were produced for use in small diameter (<9-5/8") casings. After several telephone calls, our investigation resulted in our contacting the inventor of the original GO bridge plug, Mr. Jamie Terrell. Mr. Terrell is currently employed by Halliburton Energy Services (HES) and his research facility/office is located in Ft. Worth, TX. We provided Jamie Terrell with the technical specifications for the casing remediation bridge plug, and after review he indicated that, with some design changes and proof testing, a bridge plug could be produced to meet our requirements.

Concurrently, a visit was made to TAM International, Inc., Houston, TX by both Sandia and Unocal staff to review inflatable packer designs and discuss our requirements for casing remediation. The main limitations to using inflatable packers for this project were the high temperatures that the inflatable packer elastomers would encounter in the Geysers geothermal wells. The reliability of the inflatable elements is related to the expansion ratio and peak working temperature. An expansion ratio of approximately 2.7:1 was required for this work, since the maximum packer size would be limited to 4.00" O.D. to fit through the 4.50" minimum opening in the deformed casing and the I.D. of the 11-3/4" casing is 10.88". At this expansion ratio, combined with a peak well temperature of 450° F, TAM did not recommend using their packer. However, a test was arranged by Unocal and TAM of a new elastomer design that might meet the project requirements. This test was conducted at Schlumberger Inc.'s test laboratory in Sugarland, TX. The test results were inconclusive and scheduling requirements did not permit further evaluation and testing of this packer elastomer for use on this project.

A meeting to discuss the casing remediation project and select a packer design was held by Unocal at their offices in Santa Rosa, CA on 4/3/98. Attendees included staff from Sandia, Brookhaven National Laboratory, HES, Baker Oil Tools, Calpine, and Bill Livesay, a Sandia consultant. The modified HES thru-tubing bridge plug was selected as the best option for a casing plug based on the design specifications as well as the project schedule. It was also determined that the most desirable method to deploy this plug would be on coiled tubing. This would save time since dump bailer runs, for emplacing the sand and/or cement on the bridge plug, could be eliminated. Sandia initiated a contract with HES, Fort Worth to develop and test a modified thru-tubing bridge plug that would meet the project requirements. The contract specified that the plug should be deployed on coiled tubing, set in the casing using nitrogen gas, and meet all other specifications previously defined for the casing remediation bridge plug.

Development Testing

A.) Development Testing at the Fort Worth Facility

The thru-tubing bridge plug (BP) consists of a collapsible metal petal basket and four collapsible support dogs all attached to a center support shaft. The petal basket is covered with a high temperature cloth bag made from Nomex material. The cloth bag helps to prevent the sand from falling through the voids between petals. The support dogs contain six arms that are deployed by springs that force the arms out against the casing wall. When deployed the support dogs secure the BP in the casing by digging into the casing wall with high strength steel tips on the end of the six arms. The dog assemblies are positioned so two sets support the BP against down loading and two sets prevent upward movement. Likewise, the petal basket is spring loaded to force it open and out against the casing wall when deployed. A shroud or sleeve around the outside of the BP retains and protects the dogs and petal basket until it is removed for BP deployment after insertion in a casing.

To test the shroud/sleeve operation, the mechanism was set up outdoors on a concrete pad. Only the shroud mechanical action (no BP inside the shroud) was tested. To operate the shroud it was connected to the domestic water supply with a garden hose. The water pressure was used to operate the shroud, this simulated shroud operation with nitrogen gas on coiled tubing, and permitted a safe low-pressure hydrostatic test. When pressure is applied to the inside of the shroud support tube, the shroud is forced up around the outside of the support tube. As the shroud travels up the tube the BP would be uncovered, exposing the dogs that support the shaft and the petal basket in the casing. The shroud mechanism operated as intended and slid up the support shaft with a steady smooth movement.

To confirm the operation of the BP and to test it's mechanical strength for supporting sand and cement in a casing, a second test was conducted. A ten foot length of 11-3/4", 54#/ft, grade K-55 steel casing was purchased. The casing was positioned horizontally on two dollies for BP installation. The BP was installed in the shroud mechanism and this assembly was then positioned inside the casing. The shroud and BP were successfully deployed in the test casing with domestic water pressure. Later, the entire assembly (BP and casing) was lifted with a test facility bridge crane and positioned vertically.

To verify that the sand load on the BP was acceptable, we poured 200 pounds (~3 ft. of depth) of sand directly onto the petal basket. A BP deflection of less than 0.25" was measured from the top of the casing. Theoretical and practical experience has shown that after the dry sand exceeds about 2 ft. of depth on the petal basket, it bridges to the casing wall. Only a slight additional load is carried by the BP when more sand or cement is added because the rest of the load is bridged to the casing wall by the sand. To verify this, an additional 150 pounds of sand was placed on the BP. This brought the sand level in the casing above the top of the BP assembly. To apply additional down loading on the BP, Jamie designed a load frame that could be secured to the casing and used to push or pull the BP. To push from the top, a 10" diameter X 0.5" thick steel plate was placed on the sand above the BP. A hydraulic jack was positioned between the load frame and the steel plate and a load cell was placed between the hydraulic jack and the load frame. A 3" square tubing column was positioned between the steel plate and the hydraulic jack.

Our design specifications required that an additional 50 feet of cement must be placed on top of the two feet of sand on the BP. Since the liquid density of cement is ~ 16 #/gal or 1 psi per foot of depth, and the cross-sectional area of the casing ID is ~93 sq. in., then the 50 feet of cement will apply about 4650 pounds of additional load to the BP.

A peak load of 5000 pounds, as measured with our load cell, was applied to the top of the sand using the hydraulic jack. A total BP deflection of 0.124" was measured with a dial indicator gage, attached to the base of the hydraulic jack, when the 5000 pound load was applied. Knowing that the sand breached the load to the casing wall, a second load test was conducted to verify the maximum load that could be applied to the BP without sand. The test assembly was again lifted and positioned back on the dollies, horizontally. The load frame was removed from the top of the casing and secured to the bottom so the BP could be pulled from the bottom side. A yoke was attached to the bottom of the BP center shaft. A load cell was attached to this yoke and to a hydraulic pulling cylinder. The hydraulic cylinder was in turn attached to the load frame. The hydraulic cylinder applied a pull load of 6000 pounds to the BP with no detectable movement of the BP inside the casing. This is an equivalent load of 64 feet of cement being applied directly to the BP without the sand bridging it to the casing. A test to failure was not done since the loads applied were considered to be in excess of those expected during field use.

Concerns were raised about pumping sand through 2" diameter coiled tubing into a hot geothermal well, the sand may dry out and bridge in the coiled tubing. It was decided to change the BP requirements to eliminate the sand and apply 10' of cement directly to the BP petal basket. After this 10' of cement hardened the additional 190' of cement could then be applied with another coiled tubing run. To test the bridge plug with cement on the petal basket instead of sand, several lab tests were conducted. A petal basket with the cloth bag was deployed in a test casing and cement was poured onto the basket. Only a small amount of cement flowed through the BP petal basket. It was believed that the cloth bag of the petal basket would block and hold the cement for a sufficient amount of time to allow a 10' column of cement to harden. To test the cement only BP, it was decided to utilize the previous deployed BP in the test casing containing the sand. The sand was removed and an additional section of casing was welded to the original casing to extend its length so there was 10' of casing from the BP petal basket to the top of the casing. The casing was mounted vertically and the cement was pumped into the top until the casing was full. Only a small amount of water was observed below the BP, and no cement filtered past the petal basket. After the cement cured, the casing was positioned horizontal and cut in half along the length of the casing. After cutting, it was noted that not all the sand was removed from the first test casing prior to emplacing the cement. However, the success of this test did not depend on the small amount of sand left in the casing and the placement of cement directly on the petal basket was approved.

B.) <u>First Field Test at the Midland, TX Facility</u>

A second BP was fabricated for a full-scale field test. To test the operation of the BP in an environment that modeled a typical Geysers well a test was conducted in a 40' length of 11-3/4", 54#/ft., steel casing provided by Unocal. The BP was to be set in the casing on coiled tubing using nitrogen gas to remove the shroud and deploy the BP. Ten feet of cement was then to be pumped onto the BP petal basket, again using nitrogen gas to push a wiper and thus the cement through the coiled tubing, as required in our specifications. Doug Love, a Halliburton Coiled Tubing and Nitrogen Tech Specialist from Midland, TX was able to provide a test site for this full scale field verification test in a timely manor. The site was on HES property located between Midland and Odessa, TX and provided convenient access for trucks and equipment.

A "Rat Hole" drill rig was used to air drill a 38' deep hole on the site, and install the 40' test casing in the hole. The test casing had a cone welded to the bottom to guide it in hole and to prevent the casing from being cemented in the hole, if the BP did not contain the cement. A flange was welded to the top of the casing to mate with the coiled tubing stripper. The BP was unpacked, inspected, and assembled prior to attachment to the coiled tubing. The BP was attached to the coiled tubing below the injector and stripper. The BP was then lowered into the casing and the stripper was attached to the top flange.

This test was conducted on 9/10/98. The end cap of the BP shroud assembly was secured with shear pins that were designed to break when 1200 psi of nitrogen gas was applied to the shroud removal piston. This pressure requirement was selected to provide a large enough pressure spike, at shear pin failure, to be seen at the surface if the BP was set at 800' or deeper in a Geysers well. The BP was set as intended with nitrogen gas. The shear pins broke at 1297 psi and gas vented from the casing through an exhaust valve on the stripper. This indicated that the shroud was off the BP and after all the nitrogen vented from the coiled tubing the cement and wiper was placed in the tubing. The cement was then pushed through the tubing and onto the BP petal basket with the wiper, as intended. The wiper did not seat correctly in the catcher and nitrogen gas flowed into the casing after the cement was in place. The wiper design was later changed to eliminate this problem.

The cement was allowed to cure overnight. Then the casing was rigged, lifted from the hole, and laid down for dissection and inspection. The cone was torch cut from bottom of the casing. Cement was found in the cone indicating a breach of the BP petal basket. Sectioning of the casing revealed that cement filled the casing well above the BP and that the BP petal basket did not support the cement. More than the intended 10' of cement was pumped into the casing, but this was a calibration problem and was not the cause of the BP failure. We continued to cut apart the casing and removed the BP. Examination of the excavated BP showed that the petal basket petals were twisted, bent, and broken off the BP. The assumption was that the exhausting nitrogen gas from the 1300 psi shroud removal operation caused enough turbulence in the casing to destroy the petal basket before the cement was pumped. Discussions were held between HES, Unocal and Sandia to arrive at a design modification that would eliminate this problem. The selected solution was to only remove enough of the BP shroud, with the high-pressure nitrogen gas, to expose one set of dogs. This would allow the petal basket to remain inside the shroud while the nitrogen gas vented from the coiled tubing. After nitrogen venting was complete, the remainder of the shroud could be pulled off the BP with the coiled tubing. To verify this modification and to verify that the petal basket would indeed support 10' of cement a second test at Midland was planned.

C.) Second Field Test at the Midland, TX Facility

Design modifications were made and the new BP design was assembled in Ft. Worth and shipped to Midland for the second test. The same test bed hole used previously was uncovered, inspected and readied for this test. A second 40' long 11-3/4" steel casing, provided by Unocal and modified by HES, as before, was delivered to the site. The casing assembly was then rigged, lifted and placed in the test bed hole.

The second test was conducted on 10/14/98. The new BP was assembled for attachment to the coiled tubing. The BP was attached to the redesigned wiper/catcher/clean-out assembly that was in turn connected to the end of the coiled tubing. The assembly was lowered into the test casing and the flange was secured. The BP was run in the casing to tag the bottom. The BP was then pulled up 10 feet to position it for the test. Nitrogen gas was pumped into the BP through the coiled tubing. The shear pins broke at approximately 1300 psi and the nitrogen vented from the coiled tubing through the casing as intended. This operation set the bottom dog assembly and the coiled tubing was now pulled up to expose the remaining dogs and the petal basket. We intended to pull up far enough to break a small wire rope cable attached to the BP and to the shroud assembly that was attached to the coiled tubing. This break cable was to provide a weight indicator signal that the shroud was pulled up far enough to completely set the BP. We did not see any indication of the 1000-pound load from the breaking cable on the load indicator in the coiled tubing rig. After pulling up about 11', it was decided that we were off the BP. We stopped and pumped cement.

Using an improved measuring technique, approximately 1.25 bbl of cement was pumped into the coiled tubing and the wiper was inserted behind the cement. The wiper was then pressurized with nitrogen gas to push the cement through the coiled tubing and onto the BP. The cement was pushed with the wiper as intended and after the wiper seated in the catcher assembly the nitrogen was vented, at the surface, from the coiled tubing. The coiled tubing was pulled up to zero depth indication and the flange bolts removed. The shroud was then lifted out of the test bed, washed and removed from the wiper/catcher/clean-out assembly. The wiper was then again pressurized to 1900 psi to open the clean-out ports on the catcher assembly and the coiled tubing was flushed with water and cleaned.

The cement was viewed from the surface and measured to be 22'-5" from the flange to the top of the cement. This was where it was expected to be if we actually pumped 10' of cement on to the BP petal basket. We waited overnight for the cement to cure. The casing test bed was again rigged and lifted from the hole and positioned on the ground for sectioning. The bottom cone was then cut off the casing. No cement was visible in the casing below the petal basket, and less than one gallon of diluted cement that filtered through or around the petal basket was visible in the cone. The casing was then sectioned to expose the deployed BP and cement plug. The test was considered a success, except for the break cable problem, everything functioned as intended. The test also demonstrated that the BP petal basket could support a 10' column of cement. To determine why the break cable gave no visible indication on the coiled tubing load indicator, the BP was removed from the test bed. The cement was removed from the top of the BP to expose the break cable. The cable appeared to have pulled out of the clamp on the shroud assembly instead of breaking. This cable attachment design would have to be changed on future BP assemblies to insure that the cable would break before pull out can occur. The entire BP assembly was then packaged and returned to the HES Ft. Worth facility for additional post test analysis.

Conclusion

Through a rapid development and testing program, a Halliburton thru-tubing BP has been certified for use in geothermal well casing remediation applications at The Geysers geothermal field. This BP meets or exceeds all the technical requirements for this application and can be deployed on coiled tubing and set in a steam filled, non-flowing, well casing, using nitrogen gas. Up to ten feet of cement can safely be placed on the BP petal basket. After this initial cement cures, additional sand and/or cement can be positioned on the BP to secure the well for remediation work. The BP can be drilled over and removed after casing remediation work is completed. These BP's can be readily modified, by HES, to accommodate various size casings and could be deployed on wireline, if necessary.

A BP based on this design was procured and used, by Unocal, during casing remediation work at The Geysers. The BP functioned as intended during this operation, although other problems resulted in failure of the actual remediation work[3]. Future casing remediation work, that requires a plug for milling or other operations, can utilize this technology.

This BP has been named the Special Application Coiled Tubing Applied Plug (SACTAP). The SACTAP has a maximum outside diameter of 3.75", is 100" long, and weighs approximately 200 pounds. SACTAP bridge plugs can be purchased directly from HES. The HES contact for procuring SACTAP plugs is Mr. Jamie Terrell, Manager, Chemical/Physics Laboratory, Halliburton Energy Services, 1100 Everman Parkway, Fort Worth, TX 76101-1936. He can also be reached at 1916 Christopher Dr., Ft. Worth, TX 76140, Mobile Telephone 817-683-3303. A six to eight week lead-time is required for fabrication, assembly and delivery.

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