Polyurethane Grouting of Rye Patch Lost Circulation Zone

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Abstract
Polyurethane grouting has been successfully applied to a lost circulation zone in a geothermal well at Rye Patch, NV. Previously, this zone had resulted in the temporary abandonment of the well after conventional cement plugs had been unsuccessful. The techniques applied to grouting with polyurethane were adapted from civil engineering where polyurethane is becoming the grout of choice for sealing boreholes with large voids and high cross flows.

Background
Lost circulation is one of the most persistent problems associated with geothermal drilling accounting for 10-20% of total drilling costs. Lost circulation can result in numerous other drilling problems including stuck drill pipe, damaged bits, slow penetration rates, and collapsed boreholes. Plugging lost circulation zones remains a very difficult and costly part of drilling geothermal wells especially when cross flow is encountered.

Mt. Wheeler Power was awarded a Geothermal Resource, Exploration and Development (GRED) cooperative agreement by DOE to test the productivity of the intersection of the Rye Patch fault with a major thrust fault zone, identified by a 3D seismic survey. Testing of this potential production zone required the reopening of a well that had been temporarily abandoned because of total lost circulation with high cross flows. Twenty cement plugs, including 15 conventional, two thixotropic, and three with foam cement, were unsuccessfully tried in attempts to plug the lost circulation zone.

Polyurethane has been successfully used in core drilling operations to stop lost circulation and stabilize boreholes (Langan). However, previous attempts to apply polyurethane grouting to geothermal boreholes have not been successful (Loeppke et al.). As a result of recent encouraging laboratory work and the use of polyurethane grouting in civil engineering projects (Mansure and Westmoreland, 1999), Mt. Wheeler requested Sandia's assistance in applying polyurethane grouting to the Rye Patch well.

Redrilling of the well through the casing point above the intermediate reservoir was done using a dual-tube reverse circulation rig: Land Exploratory Drilling LM120 (Rickard et. al.). The previously installed surface 13-3/8" surface-casing shoe was set at 607' (relative to this rig). Total depth drilled before temporary abandonment was 977'. At suspension, a bridge plug with cement above it was set in this casing. Because of this plug, the polyurethane grouting had to be integrated into the GRED project rather than be conducted before the GRED project.

Pre Job Planning and Design

Appendix A contains the plan for the job. Planning of the polyurethane grouting built on recent work defining best practices for polyurethane grouting of lost circulation zones and unstable boreholes (Mansure and Westmoreland, 2000a & 2000b). These include:

- the loss zone must be packed off and the polyurethane squeezed into the loss zone,
- sufficient polyurethane must be injected to sweep the zone and become the continuous phase,
- injection time should be longer than the gel time so that the material sets during injection.

The premise on which the job was planned was based on a major lost circulation zone with cross flow from 728' to 735'. While this zone could not be plugged by conventional methods, it was assumed other lost circulation zones deeper in the well could be plugged by conventional methods. It was not known if this zone included cavities or washouts. The loss zone temperature was assumed to be of 180°F and the fluid level was assumed to be 350'. It was believed that a suitable packer location existed above the zone. Thus, the plan for polyurethane grouting was for a short interval of unknown geometry, rather than grouting the entire open-hole section to the next casing point.

A packer was required to insure the polyurethane was squeezed into the formation. Subsequent drilling scrapes off polyurethane that is merely coating the borehole wall. Discussions with oilfield packer suppliers did not identify a suitable packer (subsequent work a backup gravel system suggests how to adapt oilfield packers for polyurethane grouting). The packer needed to be drillable in case it was glued in place by the polyurethane.

High pressures (up to 4,000 psi. toward the end of the job) are used in pumping polyurethane grout, more than enough to collapse the packer if the full pump pressure should be applied to the bag. Experience in using inflatable packers in mines suggests that the packer may be protected from collapsing by a "foam" plug. The "foam" plug forms as the first polyurethane injected in the borehole rises above the loss zone.

To verify the packer did not collapse allowing polyurethane to glue the drill pipe in place, a pressure/temperature transducer was attached to the drill pipe just below the fluid level in the borehole. After the packer was inflated, to verify the packer had sealed ~20 gallons of water was dumped down the backside raising the fluid level several feet. This level was monitored throughout the job to confirm the packer did not leak. In addition to the pressure/temperature transducer, a capillary tube containing optical fiber for continuous temperature logging was used to monitor the temperature both above and below the packer. The polyurethane reaction is sufficiently exothermic that at least a 100°F temperature rise was expected throughout the zone where the grout plug forms. Pressures drops, both hydrostatic and frictional, were a significant part of planning the job.

Chemical Formulation Strategy

Based on the information available about the loss zone, it was decided to prepare for three four-drum treatments. This volume was determined based on assumptions as to the length, diameter, and nature of the loss zone allowing for ~50% expansion based on the hydrostatic head expected. Viscosity and reaction rate are critical to the success of polyurethane pumping and placement. Both viscosity and reaction rate change with temperature. It was not expected that the material would heat up significantly while being pumped from the surface to the loss zone. Pressure drops and reaction rate of the raw material at elevated temperature were tested at the factory and in the field prior to injection.

The target was for the material to gel within seconds, consistent with reaction rates required to stop cross flows in dams. However, it was considered that if the first treatment was partially successful, that the second would need to react slower to penetrate farther, that is, past or through the material of the first treatment. Thus, it was decided that the material should be prepared so that it could be adjusted at the sight. It was further decided to preheat the material before pumping it into the well. A temperature was chosen to be close to the loss zone temperature to minimize uncertainties in the viscosity and reaction rate while the material is pumped into the hole. This temperature is also low enough so as not to raise the isocyanate vapor pressure to a hazardous level.

Results

Details of the polyurethane grouting are summarized in Appendix B. For both jobs, the polyurethane grouting assembly was run in, inflated, deflated, and pulled out of the hole without a problem. The packers were retrieved and can be reused. The formulation of a "foam" plug protecting the packer apparently worked. The only thing glued into the hole and left behind to be drilled out was a stinger and attached SS capillary tube. Drilling out of these items was not a problem. The polyurethane plug proved drillable, though it did plug the reverse circulation drilling system until it was learned how to drill the material (drill it with conventional circulation should have encountered no problems.)

For the second injection, when an adequate volume of material was injected, the target zone was sufficiently plugged to lower the point of loss circulation 44 feet below the revised target. Forty-one feet of borehole was restored to close to bit gage. Subsequent drilling was made easier because of reduced water losses and improved reverse circulation drilling pressures. After the polyurethane grouting, a conventional cement plug may have been able to seal the loss zone deeper in the well.

Conclusions

The polyurethane grouting at Rye Patch showed that the process can be used to seal geothermal lost circulation/cross flow zones that are difficult to plug by conventional cementing techniques. The injection process used (adapted from dam remediation/mine dewatering) while not intended to be optimal, did not include/identify anything incompatible with good drilling practice. The process is ready for service company implementation.

Acknowledgments

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Appendix A: Polyurethane Grouting Plan

1. Drill out plug and clean out hole. Temperature and caliper log interval. Video log interval adding fluid to watch flow and pick packer set point >~4 ft. above loss zone. Determine fluid level to set check valves and determine packer inflation pressure.
2. Backfill to 4 ft. below loss zone to control placement and minimize polyurethane required.
3. Make-up polyurethane assembly placing bladed centralizers above last drill pipe joint.
4. Run-in-hole banding hoses, pressure gage cable, and capillary tubing to drill pipe.
5. If gravel system is being used, pump gravel checking gravel level with sinker bar. Drop ball to seal-off drill pipe. May have to pressure up drill pipe to seat ball.
6. Inflate packer to required pressure controlling pressure with regulator.
7. Add fluid to test effectiveness of the packer seal.
8. Pump polyurethane grout at predefined rate watching for leakage past packer.
9. Fill hole to test plug. Drill out hole. Log interval. Repeat polyurethane job if necessary.

Appendix B: Polyurethane Grouting Summary

LOGS BEFORE FIRST POLYURETHANE GROUTING JOB:
Temperature and caliper logs were run to determine the location of the lost circulation zone and a suitable packer location. The fluid level was encountered at 400', higher than expected so the check valves and packer pressures were adjusted. Figure 2 shows that the major loss of fluid occurred somewhat above 737', several feet lower than expected. The interval from 700' and 710' showed to be uniform and close to bit gage (Figure 2). This interval was examined with the video camera and the 705' to 710' was chosen for the packer. The interval from 725' to 740' was examined to determine the nature of the loss zone. A major vertical fracture was found at 728' and below. Breakouts were seen, but no washouts, cavities, or holes in the borehole wall. Thus, it was decided that the zone to be plugged was fractured and larger than bit gauge, but did not contain cavities. Watching both particles floating in the water and tell tale threads attached to the light source showed no sign of vigorous cross flow.

INITIAL ONSITE CHANGES TO POLYURETHANE GROUTING PLAN:
The length between the cross over sub and packer was reduced to 20' to reduce the time from when the polyurethane mixes until it exits the stinger. The bottom of the stinger was positioned at 735' "even" with the primary loss zone, rather than 5 feet below as had been planned for high cross flows.

FIRST POLYURETHANE GROUTING JOB:
Polyurethane grouting assembly was run into the hole setting the bottom of the packer at 710'. The bottom of the stinger was placed at 735'. Both the pressure transducer and fiber optic temperature measurements showed no signs of packer leakage during the injection. When the polyurethane plug was drilled out, the bit would take weight from 721' to beyond 741'. The fiber optic temperature measurement showed exothermic reaction below 726'. Polyurethane chunks recovered had densities from >20 lb/ft^3 to >26 lb/ft^3, close to the density expected based on the hydrostatic pressure (30 lb/ft^3). The temperature of the polyurethane at the grout pump was ~60°F. 950 lbs. of polyurethane was injected, enough to produce ~40 ft^3 of reacted volume, ~31' of borehole based on the average diameter of the caliper log for the interval (15.6"). Polyurethane grouting assembly was retrieved leaving nothing in the hole.

LOGS IN-BETWEEN POLYURETHANE GROUTING JOBS:
The temperature logs run after the first polyurethane grouting job showed no significant change in the depth of the lost zone. The caliper logs showed lining of hole from 730' to 740'. The video camera

showed polyurethane from 731' to 753' including across the fracture that had been targeted interval. The conclusion was that the penetration into the fracture was inadequate to seal the zone.

SECOND POLYURETHANE GROUTING JOB

Polyurethane grouting assembly was run into the hole setting the bottom of the packer at 710'. The bottom of the stinger was placed at 740'. Both the pressure transducer and fiber optic temperature measurement showed no signs of packer leakage during the injection. When the polyurethane plug was drilled out, the bit would take weight from 715' to beyond 756'. The fiber optic temperature measurement showed exothermic reaction below 716'. Over 3,300 lbs. Of polyurethane was injected, enough expanded material to fill over 100' of hole. Samples of both expanded and unexpanded material were recovered. Apparently significant material was injected into the formation. Polyurethane grouting assembly was retrieved, leaving the stinger and capillary tube glued in borehole.

POST JOB LOGS:

The temperature logs run after the second polyurethane grouting job showed the depth of the lost zone was now somewhat above 780'. There was no evidence in these temperature logs of the loss zone originally targeted. The caliper logs showed lining of borehole from 730' to 750' (Figure 4). The video camera encountered the flowing fluid level at about 380' (previously pouring water down the well count not raise the water level). The video camera showed polyurethane from 730' to 756'.

Figure 2: Initial temperature and caliper logs indicating 737 feet as primary loss zone.

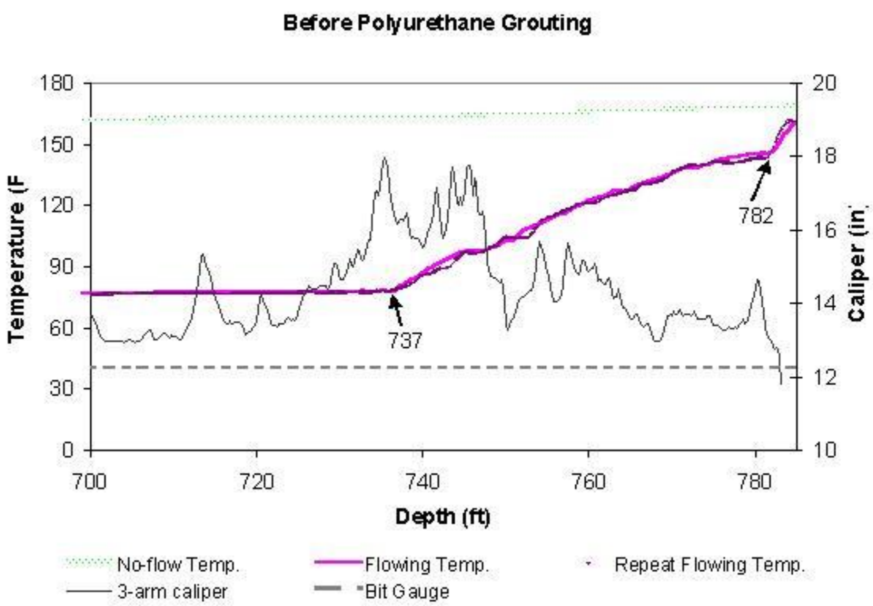


Figure 3: Temperature and caliper logs showing effectiveness of second polyurethane grouting in sealing loss zone at 737 feet.

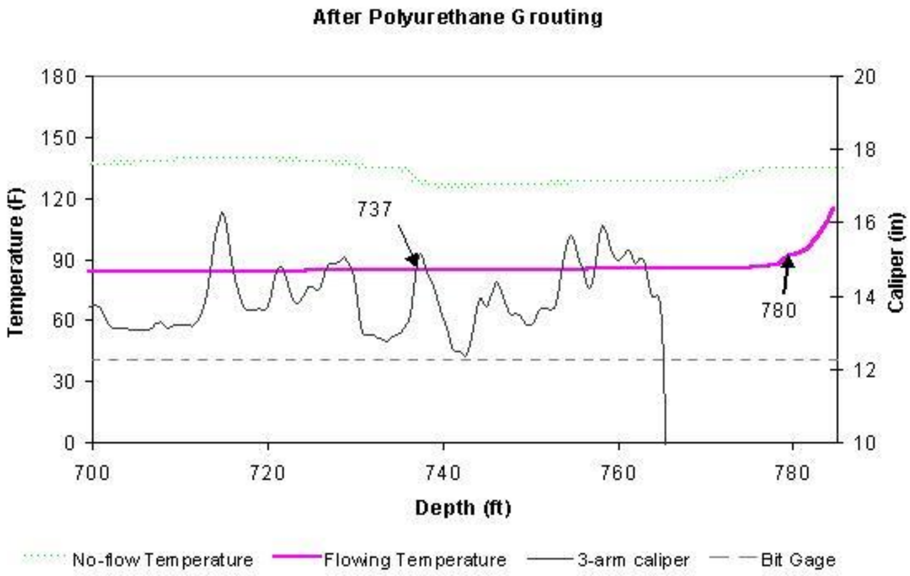
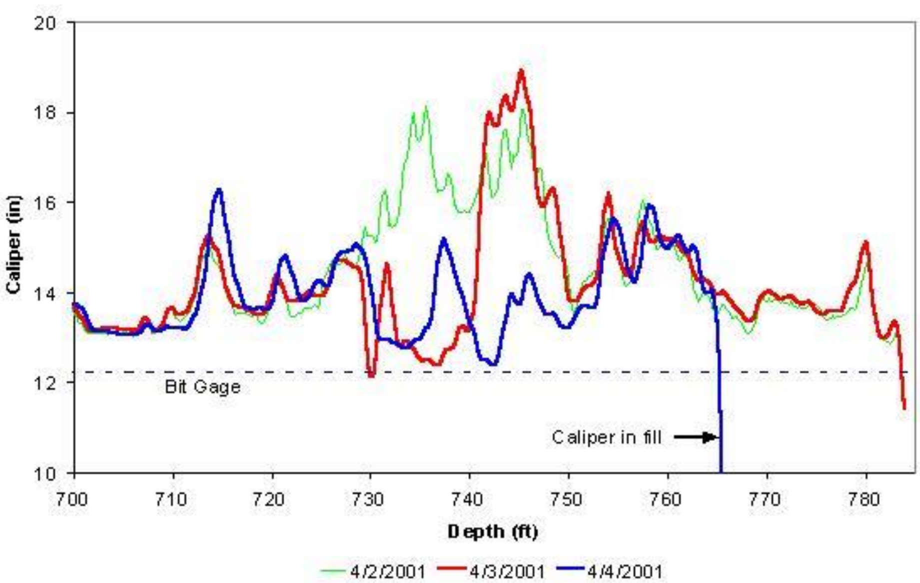


Figure 4: Caliper logs before, in-between and after polyurethane grouting.



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