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SELF-CONTAINED, RIGID-FOAM PLACEMENT TOOL FOR PLUGGING LOST-CIRCULATION ZONES*

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ABSTRACT

A solution to the lost-circulation problem in well-drilling operations has been sought for years without establishing a universally satisfactory technique or material. Recently, laboratory investigations of polyurethane foams examined their potential for plugging loss zones in geothermal wells. The data from these tests indicated that rigid foams with excellent properties for use in plugging operations could be produced under geothermal conditions. Subsequently, a concept for a family of tools for in-hole mixing and placement of rigid foams was designed, and in 1984, a prototype tool was fabricated and successfully demonstrated. After the demonstration, specifications were established for a field prototype tool for use in geothermal wells along with the development of suitable high-temperature chemical formulations. Field application of the tool began in a Known Geothermal Resource Area in the Spring of 1985.

INTRODUCTION

Lost circulation is a frequently encountered and well-documented problem in well-drilling operations. Studies show that a substantial portion of the cost associated with drilling geothermal wells can be attributed to lost-circulation problems and may increase drilling costs by 15% or more. Efforts to develop materials and techniques to control lost circulation have been ongoing for many years. Among these materials/methods was the use of rigid foams, which dates back to the 1950s when patents were issued concerning the use of such materials. In the 1960s and 1970s, various schemes and materials were used in attempts to control loss zones. Commonly, these attempts resulted in problems with control of setting time and/or pump fouling.

In the late 1970s, Sandia National Laboratories began investigating the properties of polyurethane at high temperatures for use as a material in solving lost circulation in geothermal wells. Laboratory tests of the polyurethane foam, conducted at the Southwest Research Institute in cooperation with Poly Plug, Inc., produced results indicating the suitability of polyurethane foam systems as plugging agents in high-temperature geothermal wells.

Subsequent to the laboratory material tests, Poly Plug, Inc. developed a concept for in-hole mixing and for placement of a range of closed-cell rigid foams for loss-zone control. Based on the concept, Poly Plug, Inc. designed and fabricated a prototype tool for use in wellbores. In 1984, a demonstration of the tool was conducted at Sandia National Laboratories. Following the demonstration, a cooperative effort was arranged among Poly Plug, Inc., NL Baroid/NL Industries, Inc., and Union Geothermal, Los Angeles for the fabrication and field application of a prototype tool in a geothermal environment. A description of the prototype tool and a summary of the laboratory tests, demonstration, and planned field trials follow.

DESIGN AND OPERATION

The first field application of this new concept, a self-contained, rigid-foam placement tool (Figure 1), is approximately 9.1-m (30-ft) long and 20.3 cm (8 in.) in diameter and is fabricated from a drillable aluminum alloy. The design provides for (1) storage and delivery of the tool in a charged condition, (2) two separate chambers for the two-component polymer reactants, (3) attachment to the end of the drill string, (4) capability to pump mud through the tool if required, (5) downhole activation and mixing of the chemicals, and (6) easy servicing and recharging at the well site for subsequent use if necessary. In addition, the design allows the drilling fluid to flow through the tool during tripping. The chemicals are made from a variety of low-density polymers and are selected for the temperatures expected to be encountered. The tool is easy to use, largely eliminates special equipment, and minimizes personnel training.

After a lost-circulation zone is identified, the tool is prepared for use by charging the two chemical chambers through separate filler tubes. After charging, the tool, which is attached to the end of the drill string using standard threaded couplings, is lowered by the drill string to the lost-circulation zone. Each of the two-component reactants remains separated during

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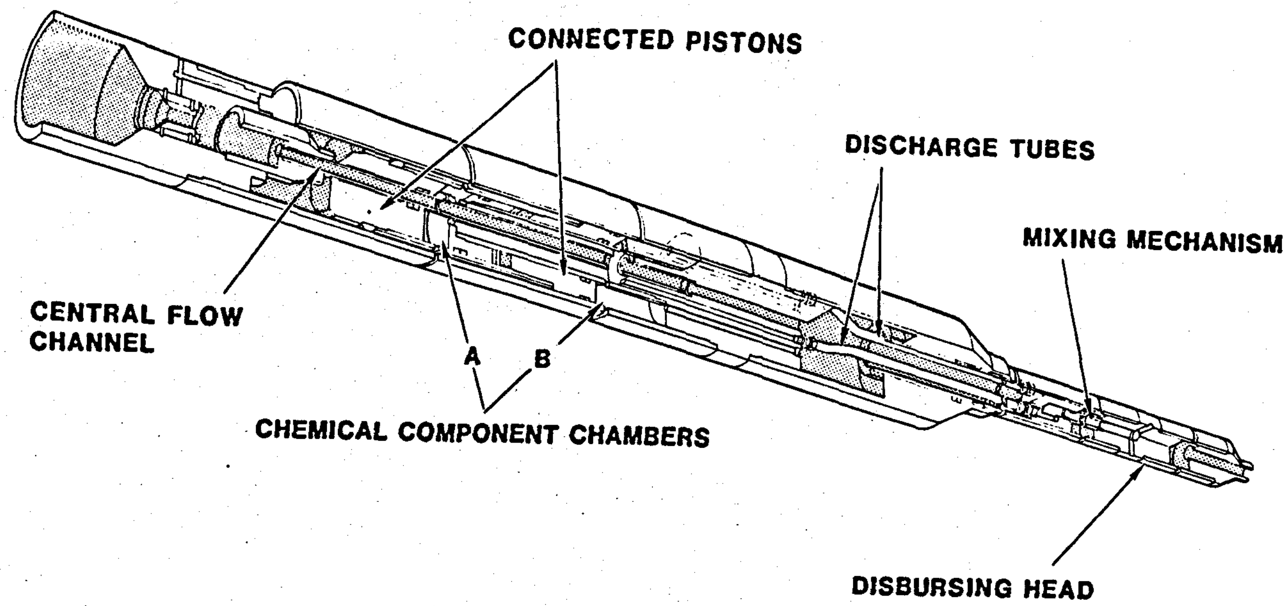

Figure 1. Schematic of Prototype Self-Contained, Rigid-Foam Placement Tool.

the trip to the lost-circulation zone. If necessary during tripping, a period of mud pumping can be included in the operation, with the fluid passing through a central channel that extends the length of the tool. This feature also avoids pulling a wet string.

After the tool is positioned with the chemical disbursing head, or "stinger," extending into the lost-circulation zone, functioning of the tool is initiated by dropping an activator ball down the drill string. On reaching the device, the activator ball shuts off the mud flow through the central channel. The resulting pressure shears pins, opening a port to a channel leading to two connected pistons, one at each chemical chamber. The fluid pressure drives the pistons, discharging the chemicals via exhaust tubes through the mixing mechanism. The reacting chemicals expand through multiple ports in the disbursing head and into the loss zone.

When the chemicals have been discharged from their chambers, pumping pressure is increased. This increase in pressure reopens the central flow channel in the tool, restoring mud flow through the tool. After removal from the drill string, the tool is readily serviced on the surface for reuse by recharging the two chemical chambers, replacing the mixing mechanism, and cleaning out the multiple ports in the disbursing head.

Expansion of the chemical plug into the loss zone is accomplished in a matter of minutes. During the expansion process, the chemical mixture generates its own driving power to penetrate the loss zone. The setting time of the chemical (which can be adjusted by selecting the appropriate reactants) is minutes in contrast to hours for cement. In the current prototype, a typical charge of chemicals is about 0.14 m^3 (5 ft^3) and can be expected to expand to a plugging volume of about 1.13 m^3 (40 ft^3), with a density of about 160 kg/m^3 (10 lb/ft^3).

The Poly Plug, Inc. chemical system is a polyurethane, two-component system consisting of an "A" side, *N:C:O.* (an isocyanate), and a "B" side, a polymer containing amino and hydroxyl groups. The two components react when they come together in a static mixing chamber. Doyle (1971) has described the reaction of the polyurethane components.

While most urethane components react instantly with water, and even rapidly absorb water, the chemical system is especially designed not to absorb appreciable amounts of water. Once mixed and in position in the loss zone, the foam produced will only react latently with water at the mixed-foam surface. This small amount of reaction provides a tremendous bond to the strata in the loss zone. The special formulation also allows for the expansion of the foam ingredients, while in the presence of hydrostatic pressures downhole. Temperatures do, however, affect these formulations. Therefore, for best results, five basic formulations are available for use within a plus/minus 14°C (25°F) range at five temperatures. The highest temperature formulation at present is for reacting at 232°C (450°F) and above. Work is continuing on higher temperature formulations, with the goal of a formulation for reacting at 316° to 343°C (600 to 650°F). In the cured form, the formulas have excellent resistance to water, oil, sulfur dioxide, hydrogen sulfide, alkalies, and acids.

DEMONSTRATION AND TEST

In 1980, Sandia National Laboratories, as part of its investigation of potential solutions to the lost-circulation problem, sponsored laboratory tests in a joint program with Poly Plug, Inc. to evaluate the suitability of using polyurethane as a lost-circulation material. The tests were conducted at the Southwest Research Institute, and emphasis was placed on the determination of the material properties of foam formed under simulated geothermal downhole conditions. The results of these tests were published in a Sandia report (Tschoepe, 1982).

Three polyurethane formulas designed by Poly Plug, Inc. were mixed, in turn, in a 122-cm (48-in.) diameter pressure vessel at four pressures, ranging from 0.1 to 6.2 MPa (15 to 900 psi), and at four temperatures, ranging from 38° to 149°C (100° to 300°F). The density of the prefoam constituents was 1,201 kg/m³ (75 lb/ft³). An inert atmosphere of nitrogen was maintained in the pressure vessel during production of the foam, and the two components of the formula were reacted within canvas bags suspended in the nitrogen environment. The test data showed that the best results were obtained under the most severe conditions: 149°C (300°F) and 6.2 MPa (900 psi). In general, the foam mixed at the higher temperatures was lower in density but had equal or better compressive strength, regardless of the pressure during reaction. In most cases, no significant difference in compressive strengths of the three formulas was noted at 38° or 93°C (100° or 200°F). No exotherm burns were observed on any samples. Pressure affected the urethane foam by increasing the density, which also inherently increases the compressive strength. Higher temperatures affected the urethane foam by improving the fluid loss, density, and compressive strength. Both temperature and pressure had an effect on fluid loss through the urethane foam. As pressure and/or temperature was increased during the formation of foam, its ability to stop fluid loss improved consistently. Based on the test results, it was concluded that high-temperature polymeric foam of low density and good physical properties can be produced under conditions equivalent to those experienced in drilling for geothermal energy.

Subsequent to the successful laboratory tests of the polyurethane foams, Poly Plug, Inc. designed and fabricated a prototype tool for downhole mixing and placement of the chemicals. In the spring of 1984, a demonstration of the tool was conducted at Sandia National Laboratories.

The demonstration was performed at ambient temperatures (21°C [70°F]) using an above-ground, simulated "loss zone" formation, fabricated from a 6.1-m (20-ft) high, 0.9-m (3-ft) diameter cardboard tube filled with water and river gravel. A "wellbore" in the center of this "formation" was simulated with 15.2-cm (6-in.) steel pipe, which had a 1.2-m (4-ft) section of expanded metal with a 1.27-cm (0.5-in.) mesh near the middle to represent the "loss zone." The test setup used to demonstrate this rigid-foam placement tool is illustrated in Figure 2. The 15.2-cm (6-in.) diameter, 6.4-m (21-ft) long, 318-kg (700-lb) tool was suspended above the test setup with the foam disbursing head or "stinger" extending into the borehole. The demonstration tool charge of chemicals was 54 kg (120 lb) or 0.05 m³ (1.6 ft³). In the test, the tool was operated by pressure from a nitrogen bottle at 2.9 MPa (425 psi). A photograph of the tool suspended above the simulated formation/borehole and ready for activation is shown in Figure 3. After discharge of the chemicals and removal of the tool, the cardboard tube was cut away, allowing the loose gravel to fall away revealing a rigid, 0.45-m³ (16-ft³) mass of gravel and polyurethane foam (~ 0.6 m [2 ft] in diameter and 1.5 m [5 ft] in length) around the wellbore at the loss zone (Figure 4). The chemical reaction time was 1.75 minutes. The volume expansion ratio of the chemicals was calculated as 7:1, and the foam density was 204 kg/m³ (12.76 lb/ft³). Samples taken from the stabilized mass were subjected to unconfined strength tests in a compression tester (Figure 5). An unconfined sample reached 11.3 MPa (1,640 psi) before failure. A much higher strength can be expected under the confined conditions down hole.

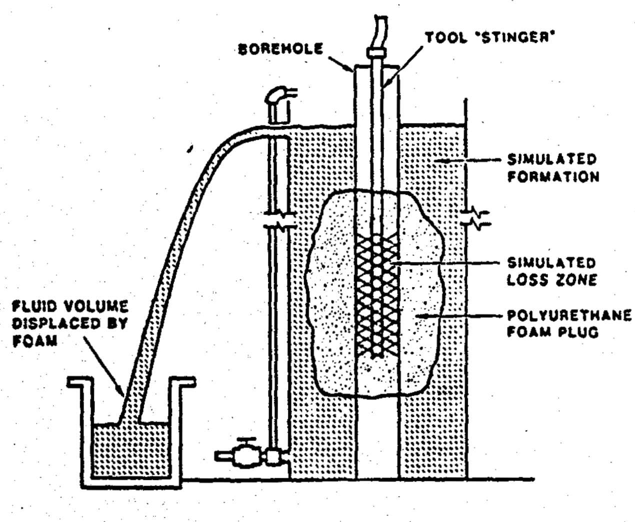

Figure 2. Schematic of Test Setup Used To Demonstrate the Rigid-Foam Placement Tool.

In late 1984, Poly Plug, Inc. conducted laboratory tests using 196°C (385°F) steam to qualify the tool and seals for field trials. Chemical formulas for field application were also qualified for use at temperatures up to +204°C (+400°F).

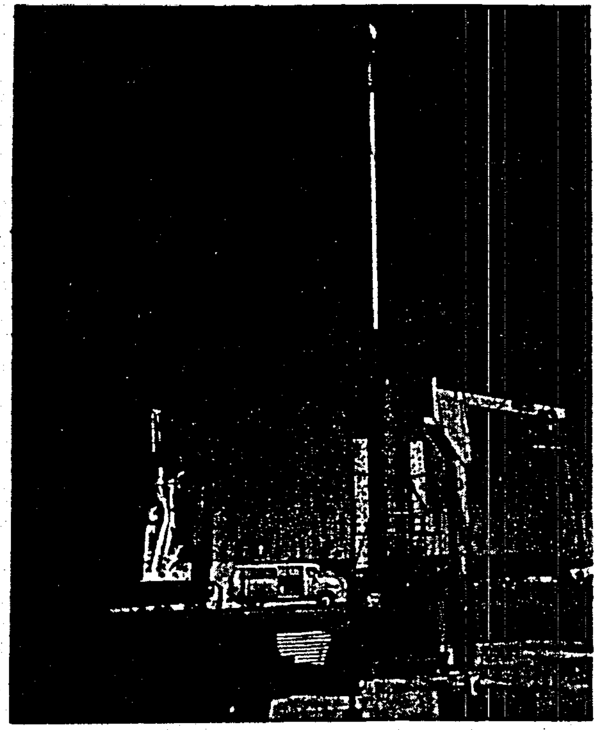

Figure 3. Photograph of Test Setup for Demonstration of the Rigid-Foam Placement Tool.

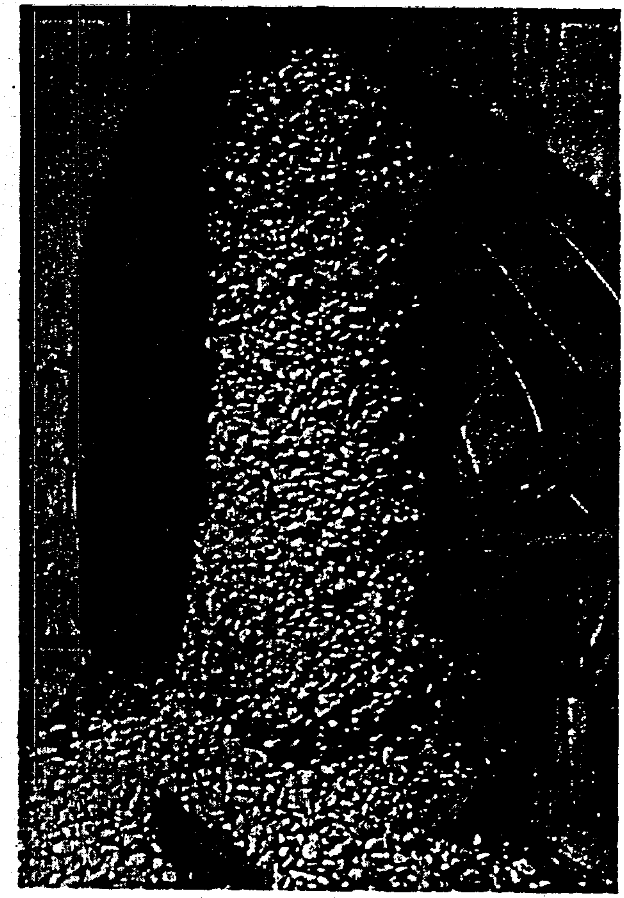

Figure 4. Photograph of River-Gravel Mass Stabilized by Polyurethane Foam Discharged from the Rigid-Foam Placement Tool.

FIELD APPLICATION

In the spring of 1985, a joint program was begun to test the tool under field conditions in a Known Geothermal Resource Area. The field trials are a cooperative effort among Poly Plug, Inc., NL Baroid/NL Industries, Inc., and Union Geothermal, Los Angeles. In addition to tailoring chemical formulations for use in several temperature ranges, Poly Plug, Inc. was responsible for the design and fabrication of two tools in accordance with specifications developed by NL Baroid in consultation with Union Geothermal. The companies are supporting the field test activities with Poly Plug, Inc. providing personnel for operating and servicing the tool on site and Union Geothermal arranging for an extended number of tool runs over a period of several months during their well-drilling activities.

The Known Geothermal Resource Area affords a challenging environment for the testing of the rigid-foam placement tool; loss zones can occur during drilling anywhere from near surface to the total depth of a borehole that may reach 2,438 m (8,000 ft). Temperatures range from near ambient in the upper part of the wells through intermediate ranges to extremely high temperatures at total depth. The test program objectives are to evaluate not only the functioning of the tool and

Figure 5. Sample of Stabilized Mass Being Tested for Unconfined Strength.

the performance of the chemical formulations under field conditions, but also to acquire information on the stability of the chemical plug and on drill-through operations. Refinement and development of new placement techniques and processes, such as rotating the tool during discharge, are also being evaluated as are the tool's durability and any design weaknesses.

SUMMARY

Both the laboratory tests of polyurethane foam and the demonstration of a prototype tool for downhole mixing and placement of the rigid foam illustrate the potential for the development of a family of tools to control loss zones in wells. The tools should also have application to other operations in which fluid loss or intrusion is a problem. Field trials of the prototype geothermal-well tool should provide additional information and experience that will be used for additional tool developments based on this concept.

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