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LOST CIRCULATION TECHNOLOGY DEVELOPMENT STATUS

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David A. Glowka, Diane M. Schafer, Glen E. Loeppke, Douglas D. Scott,
Marcus D. Wernig, and Elton K. Wright
Sandia National Laboratories
Albuquerque, NM 87185
(505) 844-3601

ABSTRACT

Lost circulation is the loss of drilling fluid from the wellbore to fractures or pores in the rock formation. In geothermal drilling, lost circulation is often a serious problem that contributes greatly to the cost of the average geothermal well. The Lost Circulation Technology Development Program is sponsored at Sandia National Laboratories by the U. S. Department of Energy. The goal of the program is to reduce lost circulation costs by 30-50% through the development of mitigation and characterization technology. This paper describes the technical progress made in this program during the period April, 1991 - March, 1992.

BACKGROUND

The most costly problem routinely encountered in geothermal drilling is lost circulation. Lost circulation problems tend to be more severe in geothermal drilling than in oil and gas drilling because of the highly fractured and underpressured nature of many geothermal formations. Bridging materials used as drilling mud additives for lost circulation control in oil and gas drilling are ineffective in plugging large fracture apertures, particularly under high-temperature conditions. As a result, the standard lost circulation treatment in geothermal drilling is to fill the loss zone surrounding the wellbore with cement. This is an expensive operation in terms of both material costs and rig time spent during the cementing operation, waiting for the cement to harden, and drilling through the cemented zone to reach new rock formations. Consequently, the costs of lost circulation in a typical geothermal well may range from several thousand to several hundred thousand dollars, depending on the severity and number of loss zones encountered.

Lost circulation costs represent an average of 10% of the total well costs in mature geothermal areas (Carson & Lin, 1982), and they often account for over 20% of the costs in exploratory wells and developing fields. Well costs, in turn, represent 35-50% of the total capital costs of a typical geothermal project (DOE, 1989). It can thus be concluded that lost circulation accounts for roughly 5-10% of the total costs of a typical geothermal project. Accordingly, reducing lost circulation costs would help reduce overall project costs and help expand the role of geothermal energy in the electric utility sector.

DOE sponsors the Lost Circulation Technology Development Program at Sandia National Laboratories for this purpose. The five-year goal of this program is to develop and transfer to industry new technology to reduce lost circulation costs by 30-50%. The Level III programmatic objective adopted by DOE is to reduce the costs associated with lost circulation by 30%. This objective combines with others to produce a Level II objective of reducing the life-cycle cost of hydrothermal electricity by 10-13% through improvements in fluid production technology. Expectations for technology improvements in several areas combine to produce a Level I objective of reducing the life-cycle cost of hydrothermal-produced electricity to 3-7 cents/kWh. This compares with a cost of 4-15 cents/kWh in 1986.

LOST CIRCULATION PROJECTS

There are currently 11 projects in the Lost Circulation Technology Development Program at various stages of development and with various levels of priority. Table I lists these projects, which are grouped into three categories: technology to plug porous and minor-fracture loss zones; technology to plug major-fracture loss zones; and technology to characterize loss zones. These projects are described in Glowka (1990) and Glowka *et al.* (1991). Priority is currently being given to technology development for characterizing and plugging major-fracture loss zones. Significant progress was made in Projects 7, 8, 10, and 11 during the reporting period (April, 1991 - March, 1992). This progress is described in the following sections.

TABLE I

LOST CIRCULATION TECHNOLOGY DEVELOPMENT PROJECTS

Porous and Minor-Fracture Fluid Loss Control:
1. Bridging Model Development
2. High-Temperature Lost Circulation Material (LCM) Development

Major-Fracture Fluid Loss Control:

3. Development of Cementitious Mud Formulations
4. Development of Cementitious Mud Flow Models
5. Downhole Injector Development
6. Porous Packer Development
7. Drillable Straddle Packer Development
8. Packer Emplacement Feasibility Study

Loss Zone Characterization:

9. Wellbore Hydraulics Model Development
10. Development of Wellbore Hydraulics Data Acquisition System
11. Borehole Televiewer Fracture Characterization Study

ROLLING FLOAT METER DEVELOPMENT AND TESTING

Field Prototype Design

The goal of Project 10 is to develop a hardware and software system for acquiring and analyzing wellbore hydraulics data that would advise the driller of lost circulation as it occurs, as well as the magnitude of the loss, its location, and possible treatments. An important part of such a system would be the flowmeter for measuring the outflow rate of drilling fluid from the well. Such a flowmeter must be accurate, reliable, economical, and simple to operate and maintain. There is currently no commercially-available flowmeter that meets all these requirements for use in lost circulation detection in

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geothermal wells. The current industry standard is the paddlemeter, which meets most of the requirements but has poor accuracy.

To meet the need for an accurate flowmeter to detect lost circulation, we earlier developed and laboratory-tested the Rolling Float Meter shown schematically in Figure 1 (Glowka *et al.*, 1991). The meter (originally called the Velocity-Level Meter) operates by producing an output voltage proportional to the angle of the pivot arm to which the float is attached. The buoyant, counter-balanced float rides the surface of the fluid in the return line; thus, the output voltage is related to the float height, which is a function of the fluid level and, therefore, the flow rate in the pipe. Because of the hydrodynamics of the 9-inch circular float as it spins, the float is held to the surface of the fluid by a vacuum force that prevents it from bouncing free of the fluid surface when it encounters surface waves moving down the return line. This causes the rolling float to produce a relatively stable reading without significantly disturbing the flow. Several design variables were optimized to achieve a configuration that exhibited a high degree of repeatability and, hence, accuracy in measuring flow rates in the laboratory. During the past year, further laboratory testing was completed, the design configuration was hardened for field use, and the Rolling Float Meter was tested in the field.

Field-Prototype Laboratory Testing

Prior to field testing, further tests were conducted with the field prototype in our Wellbore Hydraulics Flow Facility (WHFF), a laboratory test facility that provides full-scale simulation of the return flow line from a well (Glowka *et al.*, 1991). Tests were conducted with barite weighting material added to the drilling mud to determine the effects of mud density and viscosity. The results, shown in Figure 2, indicate that large changes in fluid properties should have little effect on the accuracy of the meter in the field. Tests were also conducted using varying concentrations of drill cuttings collected from a drill site in order to determine the effects of rock chip concentration. As seen in Figure 3, the inclusion of up to 6% rock chips by weight to the drilling fluid has little effect upon the response of the flow meter.

Field Testing

The encouraging laboratory test results indicated that field testing of the Rolling Float Meter was warranted. In addition, it was determined that simultaneous testing of various standard and non-standard inflow and outflow measurement techniques would permit a thorough evaluation of the relative accuracy and reliability of the various measurement techniques currently available to the geothermal drilling industry. This field testing was conducted during phase-2 drilling of the Long Valley Exploratory Well, a joint U. S. Dept. of Energy - State of California exploratory well being drilled by Sandia National Laboratories near Mammoth Lakes, California (Finger, 1992). Mud flow measurements were made and recorded every one to five minutes during the 1-1/2-month drilling period for this phase of the well in August and September, 1991.

The inflow meters tested at Long Valley included a conventional mud pump stroke counter, a mud pump rotary speed transducer, a magnetic flowmeter, and a Doppler ultrasonic flowmeter. Outflow meters tested included a conventional paddlemeter, a commercial acoustic level meter, and the Rolling Float Meter.

The three outflow meters provided measures of the fluid height and thus had to be calibrated in the field to provide signals proportional to the flow rate. Calibration was accomplished by

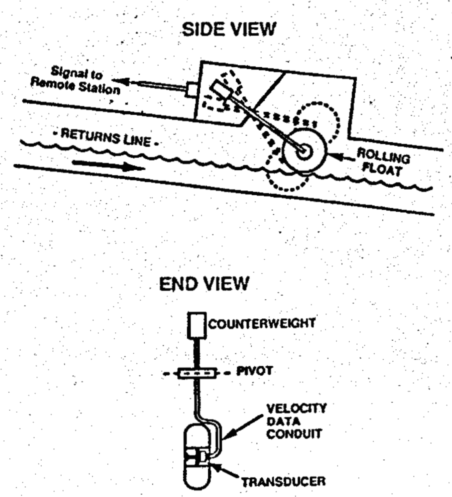

Fig. 1 - Schematic of the Rolling Float Meter.

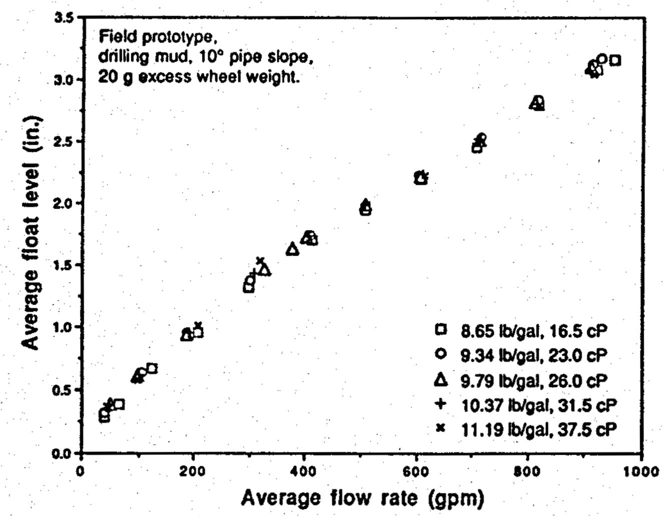

Fig. 2 - Effects of fluid density and viscosity on the Rolling Float Meter response.

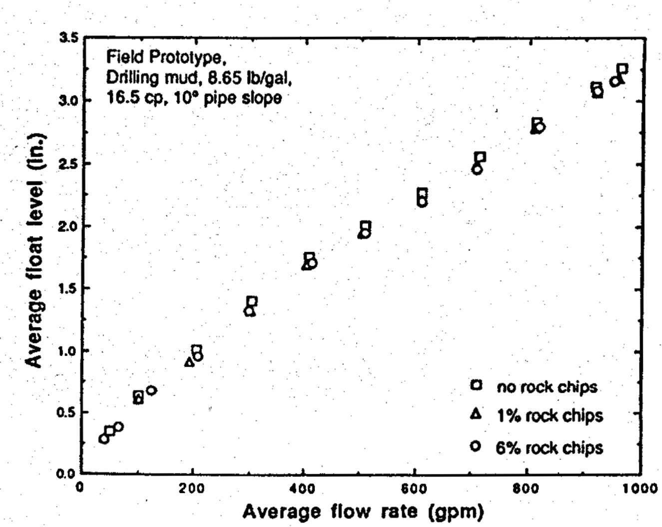

Fig. 3 - Effects of rock chips on the Rolling Float Meter response.

recording the transducer signals as the flow rate was incrementally increased from zero to 950 gpm, plotting these data, and fitting third-order polynomial equations to the data. The magnetic flow meters were used as the standard measure of flow rate, and calibrations were performed only when pit level indicators indicated no loss or gain in wellbore fluids.

The paddlemeter reading was found to be quite erratic at a given flow rate due to the tendency of the paddle to bounce off the fluid and oscillate back and forth. The apparent scatter in the calibration data was up to 35% of the average reading at a given flow rate. Furthermore, it was found that the paddlemeter reading was relatively insensitive to flow rate above 700 gpm. As a result, it was not possible to obtain an accurate calibration correlation for the paddlemeter, particularly at high flow rates. Accuracy at high flow rates is particularly important because the fluid loss rates that must be detected can be a small percentage of the normal outflow rate during drilling. The calibration data for the acoustic level meter and the Rolling Float Meter, on the other hand, exhibited very little scatter and significant sensitivity at higher flow rates. Thus, accurate calibration correlations were achieved with these outflow meters in the field.

Typical results obtained from the outflow meters under normal drilling conditions are shown in Figure 4. The accuracy of the Rolling Float Meter was typically within 1/2-1%, compared with 2-8% for the acoustic level meter and 5-15% for the paddlemeter. The Rolling Float Meter often read within 5 gpm of the magnetic flow meter reading at total flow rates over 900 gpm. The primary reason for the acoustic level meter's poor performance was that the sonic velocity of the air between the flowing mud surface and the acoustic transducer changes with temperature and gas composition. For this reason, it is necessary to monitor these states if accuracy with the acoustic level meter is expected. The poor performance of the paddlemeter was due to its insensitivity at the higher flow rates that were typical in drilling this well.

The Rolling Float Meter was found able to detect very small gains and losses in outflow rates relative to inflow rates. Typical results from a lost circulation event on August 30-31, 1991, are shown in Figure 5. Both the Rolling Float Meter and the acoustic level meter measured a drop in outflow rate. According to these meters, the loss began at approximately 6:30 pm on August 30 and ended just after 4:00 am on August 31. Loss rates as high as 56 gpm, or 6% of the inflow, were detected. The drilling crew noted a drop in mud pit levels at approximately 9:00 pm, 2.5 hours after the outflow meters first detected a loss. The drilling report for this period notes a total loss of about 200 bbl of drilling fluid. The paddlemeter measured a lower flow rate than the magnetic flowmeter throughout this entire time period. The actual loss and subsequent recovery of circulation was not detected by the paddlemeter, which is the current industry standard for measuring return line flow rates during drilling.

Wellbore fluid production during drilling was detected on September 6 and 7, when the mud logger's pit level report indicated an increase of 200 bbl. The flow meter responses are shown in Figure 6. The Rolling Float Meter measurements indicated about 5-6% greater outflow than inflow starting at approximately 2:00 pm and ending near midnight on September 6. Since the acoustic level meter read as much as 7% high throughout the day, the wellbore production of fluid was not distinctly detected with this meter. The same is true for the paddlemeter, which read approximately 5-7% low throughout the entire time period.

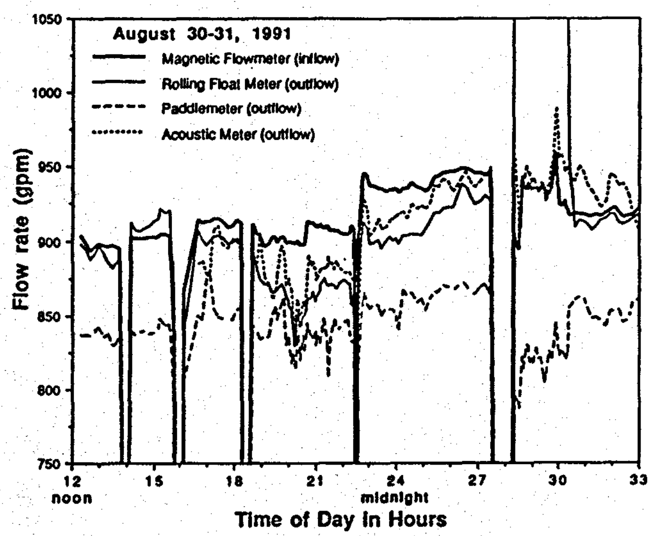

Fig. 5 - Outflow meter measurements during minor lost circulation conditions at the Long Valley Exploratory Well.

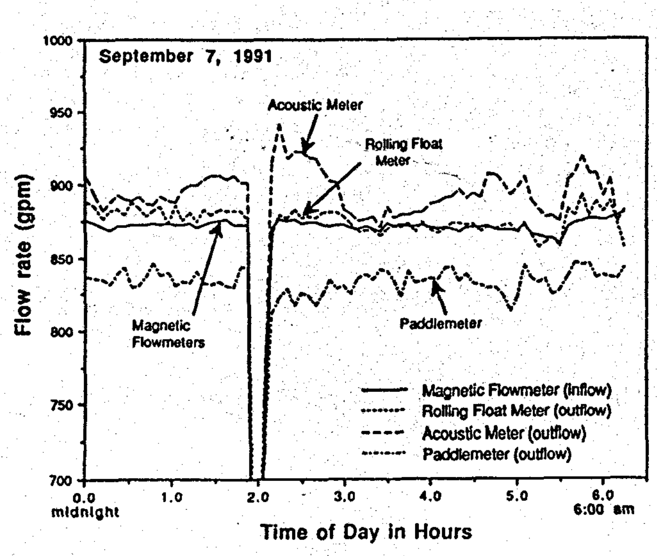

Fig. 4 - Typical outflow meter measurements during normal drilling conditions at the Long Valley Exploratory Well.

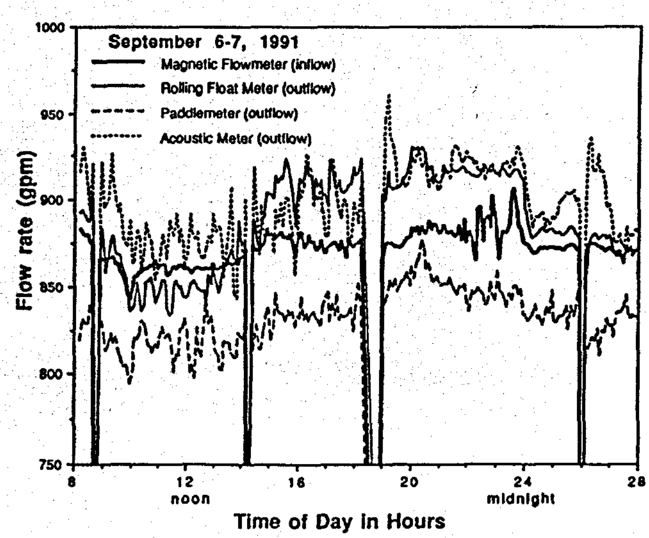

Fig. 6 - Outflow meter measurements during wellbore fluid production while drilling at the Long Valley Exploratory Well.

Problems with the prototype Rolling Float Meter were encountered during the field test. When the return mud temperature reached approximately 145°F, the sidewalls of the polyethylene float softened sufficiently to warp and become disengaged from the hubs and bearings. This problem was temporarily fixed in the field by filling the hollow float with polyurethane foam to provide structural rigidity at higher temperatures. One of the float's bearings also experienced periodic sticking toward the end of the test period, causing erroneous readings. Since the problem lasted for only brief periods of time, it was not deemed serious enough in the short remaining test time to warrant repair. These problems were addressed after the field test.

Further Development and Technology Transfer

To solve the float durability problem, the original polyethylene float was used to make a silicone rubber cast for fabricating solid polyurethane foam floats of the same size and shape as the original. A two-part foam was used that produces a strong, rigid structure with a density of approximately 6 lb/ft^3. A steel tube, cast as an integral part of the foam float, serves to hold the bearings in the float. The tester shown in Figure 7 was used to test the foam floats for durability. The float is partially submerged in heated drilling mud and rotated at a rate of approximately 130 rpm, which simulates a much greater slip velocity than that actually experienced in the Rolling Float Meter operation. These tests proved valuable in identifying a potential foam cracking problem at high temperatures. This problem was eliminated by curing the foam at 250°F for 16 hours after injection into the mold. This process produces a foam float that has withstood over 28 days of testing at temperatures of 180-195°F with no significant cracking, abrasion, or water absorption.

A simple, light-weight mud splash guard has been attached to the float and axle to prevent mud from splashing into the bearing regions and causing a potential problem. By preventing mud from accumulating on the bearings, the bearings should last indefinitely since they are subjected to very little load. Further laboratory and field testing is necessary to determine the validity of this assumption, and testing in the float durability tester is currently underway.

Near-term plans for the Rolling Float Meter are to conclude the float durability testing and transfer several Rolling Float Meter units to industry for field testing. We have been in contact with several service companies interested in evaluating the flowmeter in their operations. Drawings will also be released with the expectation that users will be able to build their own meters. An attempt will be made to locate a plastic fabricator that would be willing to supply polyurethane foam floats to potential users. All other components are either commercial items or can be easily fabricated by a local machine shop.

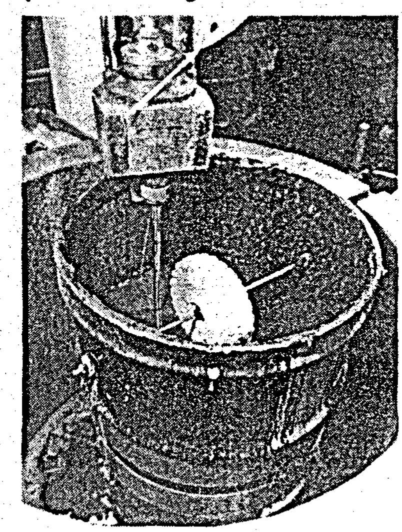

Fig. 7 - Float durability tester used for long-term testing of foam floats in hot drilling mud.

More complete descriptions of the Rolling Float Meter development process and laboratory and field test results are contained in Schafer *et al.* (1992) and Loeppke *et al.* (1992).

DRILLABLE STRADDLE PACKER DEVELOPMENT

Fabric Bag Design

The Drillable Straddle Packer under development in Project 7 is a packer assembly for isolating and directing the flow of cement into a selected loss-zone interval. The purpose is to maximize the volume of cement delivered to the loss zone and to minimize the volume of cement remaining in the wellbore. The goal of the project is to develop a low-cost packer assembly that is drillable and is left in the bottom of the wellbore at the completion of the drilling operation. To accomplish this, a new type of packer is being developed based on the use of high-strength, flexible fabric bags. A simplified schematic of the straddle packer is shown in Figure 8. The packer uses two impermeable fabric bags, one above and one below the loss zone. Inflation of the bags is accomplished simply, without valving, by the pressure differential created by the flow of cement through the packer ejection ports located in the vicinity of the loss zone.

When cement is pumped from an open drill pipe into a wellbore, particularly a large wellbore, the heavier cement tends to channel through the lighter drilling mud to the bottom of the wellbore. In many cases, relatively little cement will flow into the loss zone until the wellbore is filled to the loss zone interval with cement. As a result, more cement is required to actually plug the loss zone, and more time is required to drill through the cement that fills the wellbore. Furthermore, cement fines generated while drilling through the solidified cement have an adverse effect on mud properties and require additional mud conditioning to compensate.

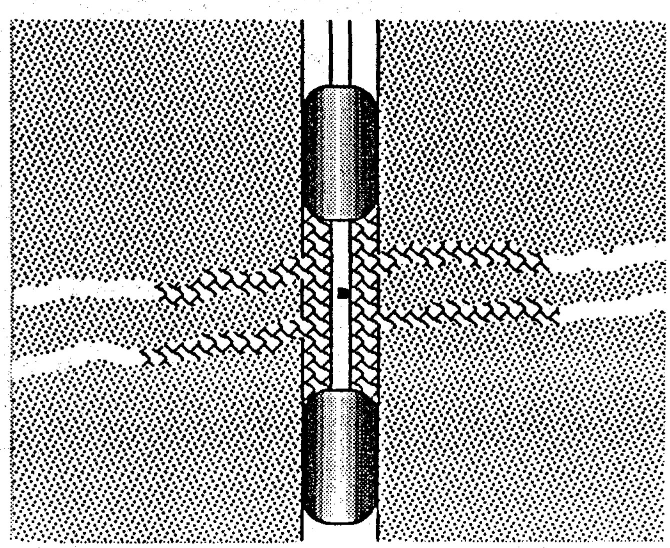

Fig. 8 - Simplified schematic of Drillable Straddle Packer, showing cement flowing out of the packer and into the wellbore and loss-zone fractures.

Because of the underpressured nature of the loss zone, a very small manipulation of the downhole pressure field would be sufficient to cause most of the cement to enter the loss zone. For instance, if the wellbore in the vicinity of the loss zone could be filled with cement and slightly pressurized relative to the hydrostatic pressure of the surrounding wellbore, most of the cement would be readily accepted by the loss zone. Flexible fabric bags located above and below the loss zone with even a small pressure capability may accomplish this objective. Furthermore, such bags should be capable of stopping or retarding the flow of other wellbore fluids into the loss zone during cement injection, thereby preventing or reducing cement dilution and improving the probability of a successful plug. Accordingly, a goal has been set to develop a flexible fabric bag capable of withstanding a 40 psi internal pressure differential.

To attain this goal, woven fiberglass-reinforced silicone rubber fabric is being used in conjunction with a unique bag design that minimizes stresses in the fabric bag. The fabrics under evaluation are only 0.015 to 0.045 inch thick but have exceptional strengths, ranging from 190 to 400 lb per lineal inch as stated by the manufacturer. Although highly flexible, the fabrics currently under consideration do not undergo significant stretch under a load.

The bag design is shown in Figure 9, which is a photograph of an inflated prototype bag assembly. The fabric is sewn into a tube, then the ends are pleated and clamped between two PVC plastic flange plates on each end of the bag assembly. An O-ring is placed between the two mating flange plates with an optimal amount of interference for maximum clamping force on the fabric. By making the fabric tube of the correct length, all hoop (circumferential) stresses in the fabric between the flanges and the borehole wall can theoretically be eliminated. By making the fabric tube slightly larger in diameter than the wellbore, the wellbore can be relied upon to provide circumferential support to the fabric, thereby eliminating all hoop stresses in the remainder of the bag. Since the fabric tube is sewn with only a longitudinal seam (which is weaker in tension that the fabric itself), elimination of the hoop stresses would theoretically allow the tube to survive internal pressures significantly exceeding the 40-psi goal.

Laboratory Prototype Testing

Prototype packer assemblies are undergoing testing in our Packer Test Facility. The facility employs a 14-ft-high length of 16-inch casing to simulate a wellbore, including fluid inlets and outlets that simulate production and loss zones, respectively (Glowka *et al.*, 1991). Tests have been conducted during this reporting period with a single fabric bag situated midway between an upper production zone and a lower loss zone. During a test, a flow of 10-15 gpm is initiated from the upper production zone into the wellbore and out the loss zone. A flow of increasing rate is then established through the packer assembly and into the loss zone to inflate the bag.

Typical results are shown in Figure 10, where the flow rate and pressure drop across the bag are shown as a function of time. These results were obtained by gradually increasing the flow rate (Q) through the packer, resulting in a corresponding increase in the pressure drop (ΔP) across the packer ejection ports and, consequently, the fabric bag. As this bag inflation pressure increased, the bag inflated more tightly against the simulated wellbore wall and sealed off the wellbore production flow (Q_W). The bag failed when the packer inflation pressure reached 24 psi at a flow rate of 170 gpm. Failure in this case was due to the fabric pulling loose from the lower flange. Work is currently underway designing and testing alternative fabric clamping methods in order to achieve the 40 psi goal.

Field Prototype Design

Significant progress was made in the design of the field prototype packer assembly. The sequences seen in Figure 11 illustrate the operation of the new design. During insertion into the wellbore, it is necessary for fluid to be able to fill the drill pipe; consequently a fluid passage through the packer is provided. This passage also allows drilling mud to be circulated through the assembly at periodic intervals for hole maintenance purposes during drillstring insertion. When the packer assembly reaches the loss zone, a 1.5-inch plastic ball is dropped into the drill pipe and pumped to bottom, where it lodges in the circulating port that extends through the extension piston. As fluid flow continues, the extension piston is driven downward, shearing the anchor pins in the lower shear guide and pushing ahead of it the extension tube, extension tube bulkhead, and shroud tube. An offset between the extension piston and the top of the shroud tube allows the shroud tube to clear each bag before the piston reaches the bag inflation ports and causes the bag to inflate. By the time the extension piston reaches the bottom of the packer assembly, both bags are unshrouded and inflated, and cement flows out the ejection ports between the two bags, into the wellbore and loss zone.

Fig. 9 - Inflated prototype flexible-fabric packer bag.

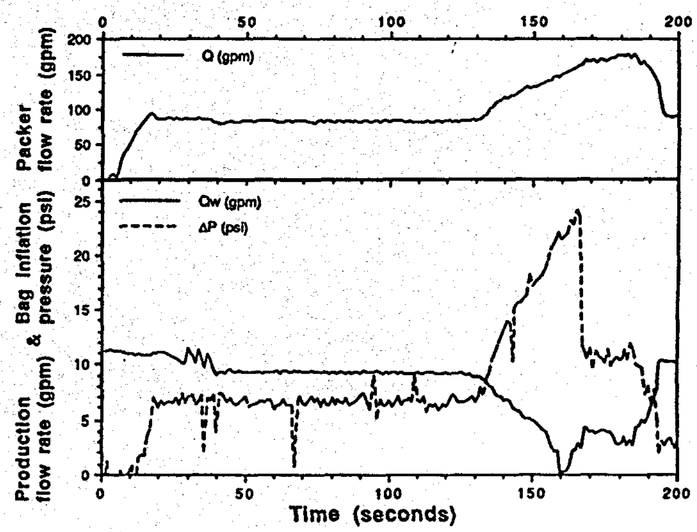

Fig. 10 - Laboratory results obtained with a prototype flexible-fabric packer bag.

The pressure differential across the packer ejection ports is a function of the number of ports, their diameters, and the density and flow rate of the cement. The pressure differential across the ejection ports is therefore readily controlled from the surface by controlling the flow rate. If the loss zone is significantly underpressured such that it readily accepts all of the cement flow, the pressure differential across the bags will be such that $P_L < P_W$. In this case, any leakage across the bag, Q_L, will be from the wellbore into the loss zone region. The bypass valve plug remains in place, and no fluid flows through the bypass valve tube.

If, however, the loss zone cannot accept the full flow of cement, the pressure in the wellbore region between the two bags will increase such that $P_L > P_W$. Since adequate leakage past the bag cannot be guaranteed in this case to prevent the bag from bursting, it is necessary for the bypass valve to open to prevent P_P from increasing to the burst point. The valve opens due to the reverse pressure differential causing the bypass valve plug to pop off, allowing excess cement to flow through the bypass tube. In practice, there would be at least one bypass tube in both the top and bottom bag. By sizing these tubes to accept the full flow of cement at a prescribed pressure differential, it is theoretically possible to prevent the bags from bursting under any type of loss-zone conditions.

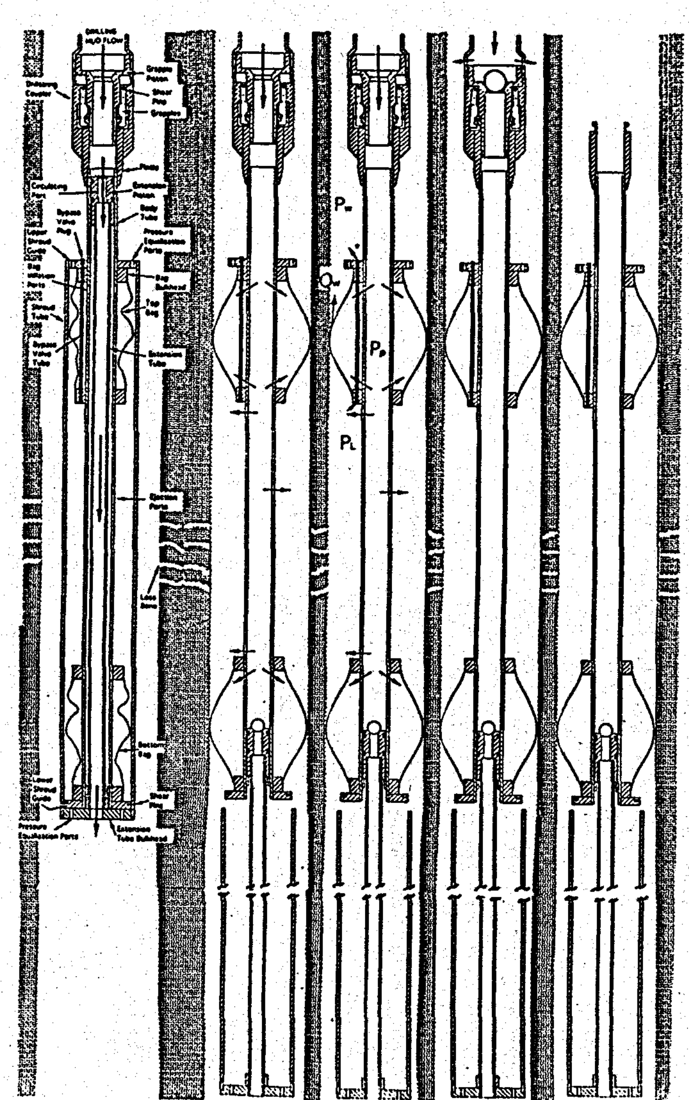

Fig. 11 - Operation of the Drillable Straddle Packer.

Once the full volume of the cement pill has been pumped, a 2-inch-diameter ball is dropped into the drill pipe and pumped downhole, where it lodges in the circulating port that extends through the grapple piston. As the pressure above the ball builds, the shear pins in the drillstring coupler break and allow the grapples to open, releasing the pintle at the top of the packer assembly. The drillstring is then withdrawn from the hole, leaving the packer assembly behind. Movement of the grapple piston also uncovers circulating ports that allow any remaining cement to be circulated out of the drill pipe. The packer assembly, made of drillable materials, is drilled through when the drillstring is returned to bottom of the wellbore for the resumption of drilling after the cement sets.

Drillstring Coupler Testing

The drillstring coupler described above was successfully tested during this reporting period. The coupler was placed in the Packer Test Facility and operated in a manner similar to that expected in the field. Pressure behind the 2-inch ball rose to 102 psi before the shear pins broke and released the packer assembly from the coupler. This release pressure can be tailored to any level in the 100 to 500 psi range by changing the diameter of the shear pins used in the coupler.

Near-term plans for the drillable straddle packer include further improvement in the pressure capability of the fabric bag end closures, then testing of a laboratory prototype packer assembly designed to evaluate the packer shroud and flow-through mechanism. Also planned within the next year is a full-scale demonstration of a packer assembly using cement in a surface or near-surface wellbore with a simulated loss zone. If successful, this development effort will then concentrate on field testing a packer assembly under actual field conditions.

PACKER EMPLACEMENT FEASIBILITY STUDY

A conceptual design study of an alternative packer emplacement method was completed under Project 8 during the reporting period. This study was contracted to Science and Engineering Associates (SEA), Inc., of Santa Fe, NM. SEA has a patent pending on an inversion technique for emplacing membranes downhole for fluid sampling in monitoring boreholes drilled around hazardous waste sites. The concept employs a thin-fabric membrane that is inverted by internal pressure and forced against the borehole wall. The similarity of the membrane to a packer assembly suggests that this inversion technique might be used to emplace downhole packer assemblies for lost circulation control (Glowka *et al.*, 1991).

Consequently, SEA was contracted to develop conceptual, advanced conceptual, and detailed designs of at least one system for emplacing a packer downhole at a depth of 4,000 ft. Several concepts were considered and carried to various stages of study. The system that was finally judged to be the most feasible in the short-term is a concept for inverting a transparent membrane filled with water and containing a downhole camera. Such a system would allow optical logging of the wellbore wall under otherwise opaque conditions. An optical log may provide superior fracture characterization to that obtained with a borehole televiewer.

Near-term work on this project includes design, fabrication, and testing of a prototype system in a shallow, near-horizontal borehole. The primary purpose will be to determine the feasibility of clearly viewing the borehole wall and associated fractures through the water envelope and transparent membrane.

BOREHOLE TELEVIEWER-FORMATION FRACTURE STUDY

The purpose of Project 11 is to develop techniques for using an acoustic borehole televiewer (BHTV) to accurately measure the thicknesses of fractures associated with lost circulation zones. Although the BHTV has been in use for many years to locate fractures and determine their spacing, dip, and strike, quantitative fracture measurement is not readily accomplished because of the effects of signal amplifier settings on the apparent size of features as seen with the televiewer. We previously developed a technique for determining the optimal amplifier settings for filtering out unwanted signal perturbations and displaying only significant fractures that may be associated with a loss zone (Glowka *et al*, 1990). This work, based upon laboratory experiments in fractured rock samples, resulted in a technique that appears to enable fracture thicknesses to be measured within 15% accuracy, if the fractures are at least 0.15 inches in thickness. Fractures as thin as 0.03 inches can be detected but not accurately measured.

During the past year, we had the opportunity to field test the technique at the Long Valley Exploratory Well. The bottom 720 ft of the well was wireline-cored and subsequently logged with the BHTV. A 150-ft section of the corehole was logged twice, once with a conventional amplifier setting that resulted in significant gray-scale sensitivity, and once with an optimal amplifier setting determined according to the previously developed technique. The return amplitude log obtained with each setting is shown in Figure 12. Also shown in this figure is a photograph of the actual core section corresponding to the logs.

Note that there is an excellent correlation between the sinusoidal fracture signatures appearing on the televiewer logs and the actual fractures in the core. Comparing the two televiewer logs, it is seen that the conventional amplifier setting results in a log that identifies many more features than that of the log obtained with the optimal gain setting. Many of the additional features on the first log are actually due to variations in borehole wall reflectivity rather than open fractures. (For instance, compare the logs with the core photo between fractures "A" and "B".) From a fracture identification standpoint, a log obtained at an optimal gain setting is more useful than one obtained with greater gray-scale sensitivity. By eliminating extraneous, non-fracture features, development of automated fracture identification and measurement software will be more easily accomplished.

It should also be noted that a given feature is generally much larger in the log obtained with conventional signal amplification than it is in the log obtained at optimal amplification. The effect is illustrated in Figure 13, which shows the effects of signal amplification on the measured span of a given fracture. These data were obtained by digitally amplifying the return amplitude signals obtained with the conventional amplifier settings near a fracture. A digital gain of one

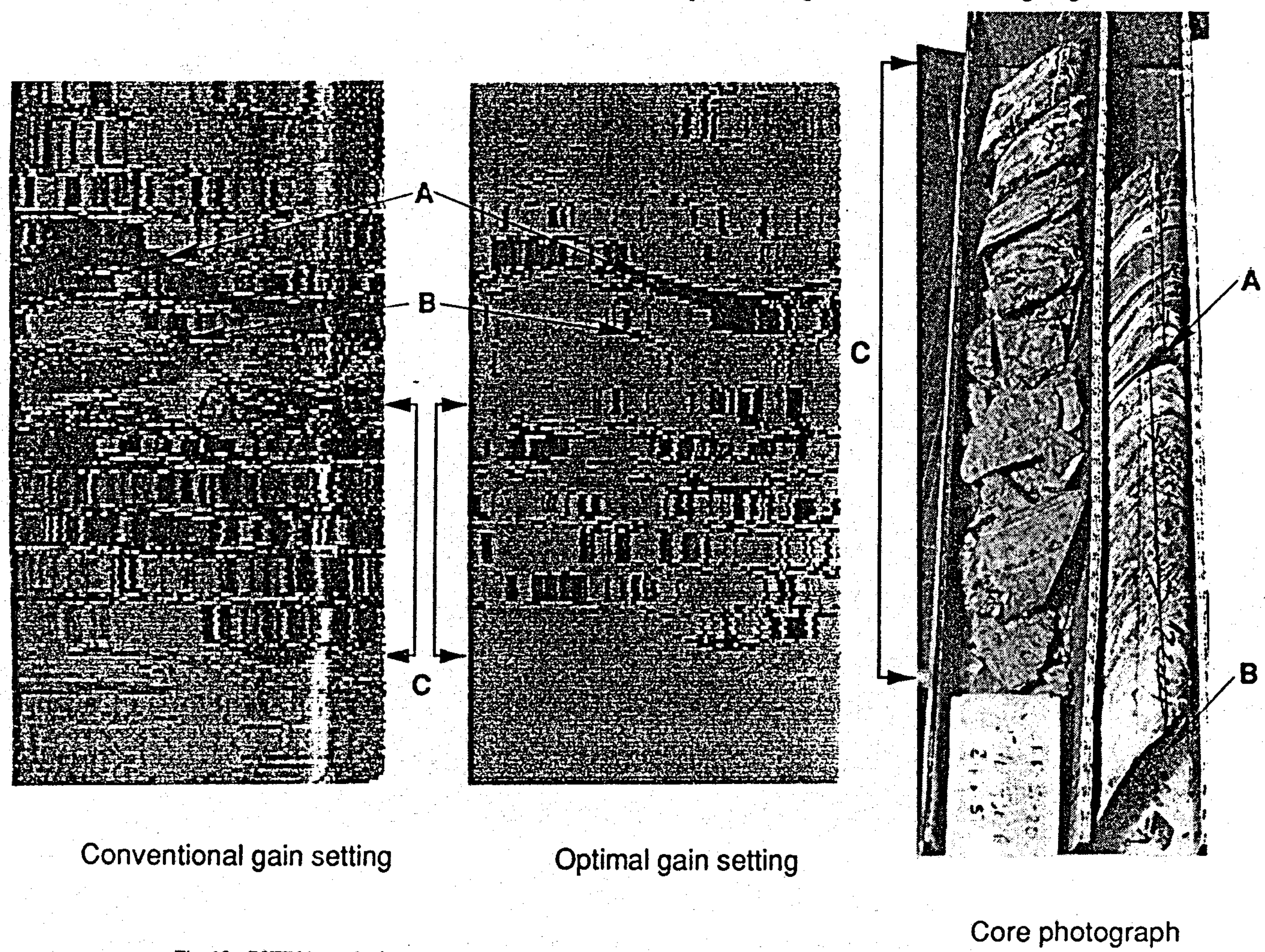

Fig. 12 - BHTV logs obtained at two different amplifier gain settings compared with photographs of the core from the Long Valley Exploratory Well.

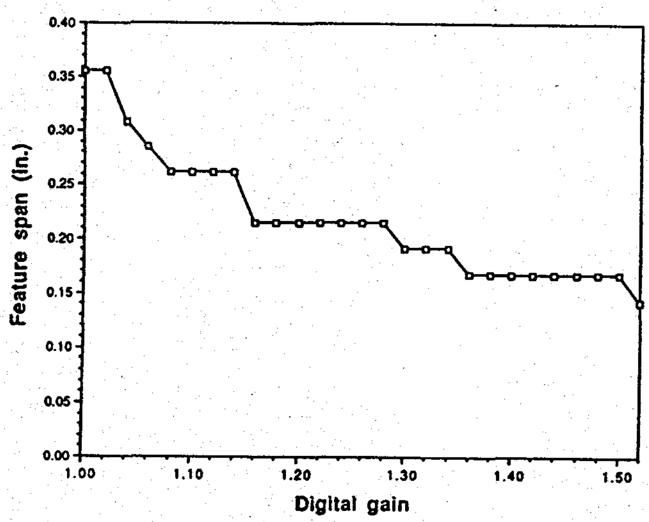

Fig. 13 - Effects of BHTV signal amplification on the measured feature span.

corresponds to the original signals. As the signals from individual acoustic pulses near the fracture are amplified, an increasing number of signals are driven to the amplifier saturation level, thereby effectively reducing the number of signal perturbations associated with the fracture. As a result, the apparent fracture span decreases with increasing amplifier gain. This illustrates the need to identify the correct signal amplifier settings for accurate measurement of fracture apertures.

Near-term plans for the BHTV study include laboratory tests with fractured rock samples to determine the effects of rock type, borehole fluid properties, and televiewer eccentricity on the optimal gain selection technique. A hardware and software capability has been built to acquire BHTV data and display it on a continuous gray-scale plotter in real-time. This capability will be used in the laboratory tests and in field tests planned for later this year at Long Valley.

SUMMARY

As described above, several lost circulation projects have significantly advanced during the period April, 1991-March, 1992. The primary accomplishments for the year are: development and field testing of the Rolling Float Meter; design and laboratory testing of prototype fabric bags for the Drillable Straddle Packer; completion of a conceptual design study of an alternative packer emplacement technique; and field testing and confirmation of the optimal gain selection technique for measuring fracture thicknesses with a borehole televiewer. Work was also performed on several other lost circulation projects but does not merit reporting at this time.

As discussed in Glowka (1990), the technologies being developed under the various lost circulation projects are estimated to reduce lost circulation costs by an average of 27-48%. These estimates are based on detailed cost and time estimates for using the various technologies in lieu of the standard cement treatment currently in common use in geothermal drilling.

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