

DESIGN, FABRICATION, INSTALLATION, AND TESTING OF AN ADVANCED WELLS/RESERVOIR MONITORING SYSTEM AT THE DIXIE VALLEY, NEVADA GEOTHERMAL FIELD

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ABSTRACT

A wellbore/reservoir monitoring system consisting of four 0.25" capillary tubing strings banded on the outside of a 1.9" hangdown string was installed in a production well at the Dixie Valley geothermal field. Two optical fibers, one single ended and one looping from the surface to 4900' and back, were installed in sealed capillary tubings to obtain distributed temperature logs to a depth below the flash point. A thermocouple was installed to both assist in calibrating the optical fibers and provide a continuous and independent long-term single point temperature of the wellbore below the flash point. A 0.094" cap tubing was installed inside a 0.25" cap tubing to continuously monitor the pressure below the flash point. The annulus of this 0.25" string is also utilized for injection of a scale inhibition chemical. This system allows the well to be kicked off with compressed air and confirmation logging with small diameter tools inside the hangdown string.

Both optical fibers degraded within days but did provide information suggesting the looped fibers produce higher quality data. The temperature profile of the well to a depth of 4900' was continuously monitored as the well was kicked off with compressed air. The thermocouple, pressure monitoring, and chemical inhibition systems have now successfully operated for six months.

INTRODUCTION

As geothermal fields age or outputs are maximized or injection augmentation programs are implemented it becomes more likely that maintaining the desired output will become more difficult. The earlier that wellbore or reservoir pressure and temperature trends can be identified and quantified, the sooner that appropriate changes to individual well or reservoir strategies can be identified and implemented. Without good quality downhole information it is

unlikely that the initiation of trends can be identified or the details of these trends followed in a timely manner.

At the Dixie Valley, Nevada geothermal field the installation of a distributed temperatures sensing (DTS) system in one production well resulted in fundamental design changes to the downhole carbonate scale inhibition system which has allowed the piggy backing of a new wellbore/reservoir temperature and pressure monitoring system onto an existing hangdown string previously used primarily to protect capillary tubing used for carbonate scale inhibition. Components of this system have now been installed in all Dixie Valley production wells.

PREVIOUS SCALE INHIBITION SYSTEM

In December 1988 the first hangdown string was installed in a Dixie Valley production well to protect the 0.25" capillary tubing strings used for carbonate scale inhibition (Benoit, 1990). These hangdown strings consist of joints of 1.9" O. D. open ended oil field tubing hanging from the wellhead. As the bottom of the hangdown strings were located below the static fluid level, compressed air is blown down through the hangdown strings to kick off the wells to commence production. After the well is flowing, the cap tubing (including sinker bars and dispersion head) is run inside the hangdown string.

It quickly became apparent that the cap tubing strings can become stuck inside the hangdown strings. Trying to retrieve a stuck cap tubing generally results in breakage of the tubing and cessation of scale inhibition. The well must then be shut in so that the hangdown string can be pulled and cleaned out. One side effect of this process was that the desire of management to risk pulling cap tubing strings to obtain regular or routine downhole temperature and pressure measurements was minimal. As this inhibition system has proven capable of operating continuously for over 1200 days the amount of

downhole data collected from the flowing production wells was minimal. The data obtained also tended to be of lower quality as they were often collected immediately following well workovers.

RESEARCH OBJECTIVES

The advent of DTS and the installation of three DTS systems at Beowawe (Benoit and Thompson, 1998) provided encouragement for Sandia National Laboratories, Pruett Industries International, and Oxbow Geothermal Corp. to embark on a program early in 1998 to install a DTS system in a deeper and hotter production well at Dixie Valley. The primary purpose of the test was to install a variety of individual optic fibers to determine which would best withstand the rigors of long-term service in a 330 to 470 °F flowing well to a depth of 5000'. The only long-term experience with DTS systems in producing geothermal wells to date has been at Beowawe and these results demonstrated that not all high-temperature optical fibers are capable of surviving in a flowing geothermal well. At Beowawe the fibers are subjected to temperatures of only 300 to 370 °F and depths of 1100 to 1200'.

A second purpose of the test was to compare the data quality from looped vs single-ended DTS fibers in the same well. This objective was added to the program at a fairly late date due to questions and concerns which had recently arisen at Beowawe. The different and larger diameter downhole hardware configuration at Dixie Valley made installation of a looped system much more convenient than at Beowawe.

In a looped fiber both ends are at the surface. The DTS operator can perform temperature measurements starting at either end. This type of system relies on one less calibration factor and in theory should be more accurate. In a single-ended system one end of the optic fiber is at the surface and one end is inside the wellbore. The single-ended results at Beowawe had produced inconsistent results with a scatter of as much as ± 10 °F.

To independently check the quality of the temperature data traversing temperature logs and a downhole thermocouple were incorporated into the system. The thermocouple would be calibrated to the traversing logs and then the DTS system could be calibrated and cross checked at any time with the thermocouple. A thermocouple may be suitable for long term temperature monitoring of wellbore temperatures below the flash point. The benefit of a DTS system is that it can provide additional information such as monitoring of flash point depth changes and should be able to assist in evaluating potential wellbore problems such as cold water leaks through liner laps. Also once rugged fibers are

identified for temperature purposes additional data acquisition such as pressure and chemistry will be possible with these fibers.

As the 1.6" inside diameter of the hangdown string is too small for state of the art flasked digital temperature tools, only smaller diameter analog tools can be utilized for confirmatory logging. A program was also included for checking the accuracy of the Pruett analog temperature tool against a Southern Methodist University digital tool. This was done in the cooler 45-14 well, which offers the highest temperatures at the shallowest depths of any of the open Dixie Valley wells.

Another initial research objective was to install a DTS system in an idle well to a depth of 8000' to 10,000' but this has not yet been implemented given the difficulties encountered to date in the flowing well.

HARDWARE DESIGN AND CONSTRUCTION

The overall hardware package was built around the 1.9" O. D. hangdown strings. The scale inhibition tubing was moved from the inside to the outside of the hangdown strings so that confirmation logs could be run inside the hangdown strings without having to risk pulling the cap tubing before each log. Once one cap tubing was on the outside of the hangdown string it is a simple matter to install additional cap tubing strings.

Two cap tubing strings were initially envisaged for the system, one for scale inhibition and one for temperature and pressure measurements. The initial design of the temperature and pressure string was for a 0.25" tubing to contain a sealed 0.156" O. D. stainless steel tubing. The inside of the 0.156" tubing would then contain a thermocouple and a sealed 0.046" O. D. cap tubing. Three different optical fibers would be installed inside the 0.046" cap tubing. The annulus between the 0.25" and 0.156" tubings would be utilized for pressure measurements as the 0.25" tubing would be connected to a downhole pressure bomb. This initial design did not provide for a looped system.

Initial fabrication plans called for the 0.25" cap tubing to be constructed around the interior components and for the 0.046" tubing to be constructed around the optic fibers. However, a recent bad experience wherein the optic fibers were damaged by the tubing fabrication process resulted in a design change to larger diameter tubing strings for fiber protection.

With this system the well could be kicked off with compressed air and confirmatory logs with small diameter temperature tools could be obtained.

Continuous temperature from the thermocouple and continuous pressure below the flash point would be recorded. DTS logs would be intermittently obtained.

As hardware construction commenced some modifications were made. First, the diameter of the system, initially at 3.5" for the pressure chamber was reduced to 2.875" allowing for easier installation through a sweeping elbow at the top of the wellhead. Second, new information from Beowawe strongly suggested that a DTS looped system should be installed to actually measure the differences in data quality between the two types of DTS systems at high temperatures. Third, manufacturing experience suggested that the cap tubings enclosing the optic fibers should be 0.25" to avoid damaging the fibers during manufacturing.

After these changes the equipment actually fabricated consisted of:

1. A chemical inhibition/pressure monitoring system consisting of 0.094" cap tubing inside of 0.25" cap tubing. The 0.094" tubing was connected to an eccentric 2 7/8" O. D. pressure chamber (Figure 1). The 0.25" cap tubing was connected to an injection head welded to the outside of the hangdown string and the inhibitor chemical is pumped via the 0.25" x 0.094" annulus.

2. A 10,000' long looped 0.025" cap tubing containing a chemical resistant fiber (Spectran Specialty Optic Company Item Number BFO5493). This cap tubing string was manufactured around a single strand of fiber. At the wellhead this looped fiber appears to consist of two individual cap tubing strings.

3. A 5000' long 0.25" cap tubing which was sealed on the bottom and contained a thermocouple and two single-ended optic fibers, the chemical resistant fiber noted above and a polycarbon coated fiber. This cap tubing string was also manufactured around the thermocouple and optic fibers. Unfortunately during preliminary testing of this cap tubing string both optic fibers broke. Ultimately this cap tubing string was slightly shortened and installed simply as the thermocouple.

4. After the damage to the single ended fibers occurred, a single replacement polycarbon coated fiber (Spectran Specialty Optic Company Item

Number BFO5179) was quickly procured and installed in another 0.25" cap tubing.

Therefore at installation there were five 0.25" cap tubing strings strapped to the outside of the hangdown string. This required drilling additional holes in the tubing hanger to allow the cap tubings to exit the wellhead.

HARDWARE TESTING

Prior to being brought out to Dixie Valley the individual components of the system were tested as follows.

1. The pressure chamber was tested to 5000 psi which is approximately 5 times the pressure to which it should ever be exposed in the wellbore.

2. The looped optical fiber was shot with an OTDR (optical time domain reflectometer) to determine its light loss characteristics and then it was stretched out on the ground. It was then rolled back up and shot again with the OTDR. This demonstrated that the capillary tubings could be rolled and unrolled without damaging the optical fiber. The cap tubing was then purged with nitrogen and sealed.

3. The pair of single-ended optical fibers were shot with an OTDR and both appeared to be broken at a length of 4750'. The 0.25" cap tubing was then unrolled and this caused multiple breaks in the fiber. In assessing the problem a few lengths of the cap tubing were cut off and this shortened the thermocouple by a few hundred feet. It appears that the optical fibers were damaged interacting with the much stiffer and larger diameter thermocouple lines.

4. The single replacement polycarbon-coated fiber was pumped into a 0.25" cap tubing with water. The water was then partially flushed from the tubing with nitrogen. This was also shot with the OTDR prior to installation to verify the fiber continuity.

INSTALLATION

Early on the morning of July 7 well 74-7 was shut in to begin the process of installing the hardware. The existing hangdown string was removed by the evening of July 7. On the morning of July 8 the wellhead was modified so that the larger-diameter system could be installed. In mid afternoon of July 8 the new system started down the well. Installation was completed on the afternoon of July 9.

Pruett Industries
 Oxbow Dixie Valley
 Temperature/Pressure/Chemical Injection System

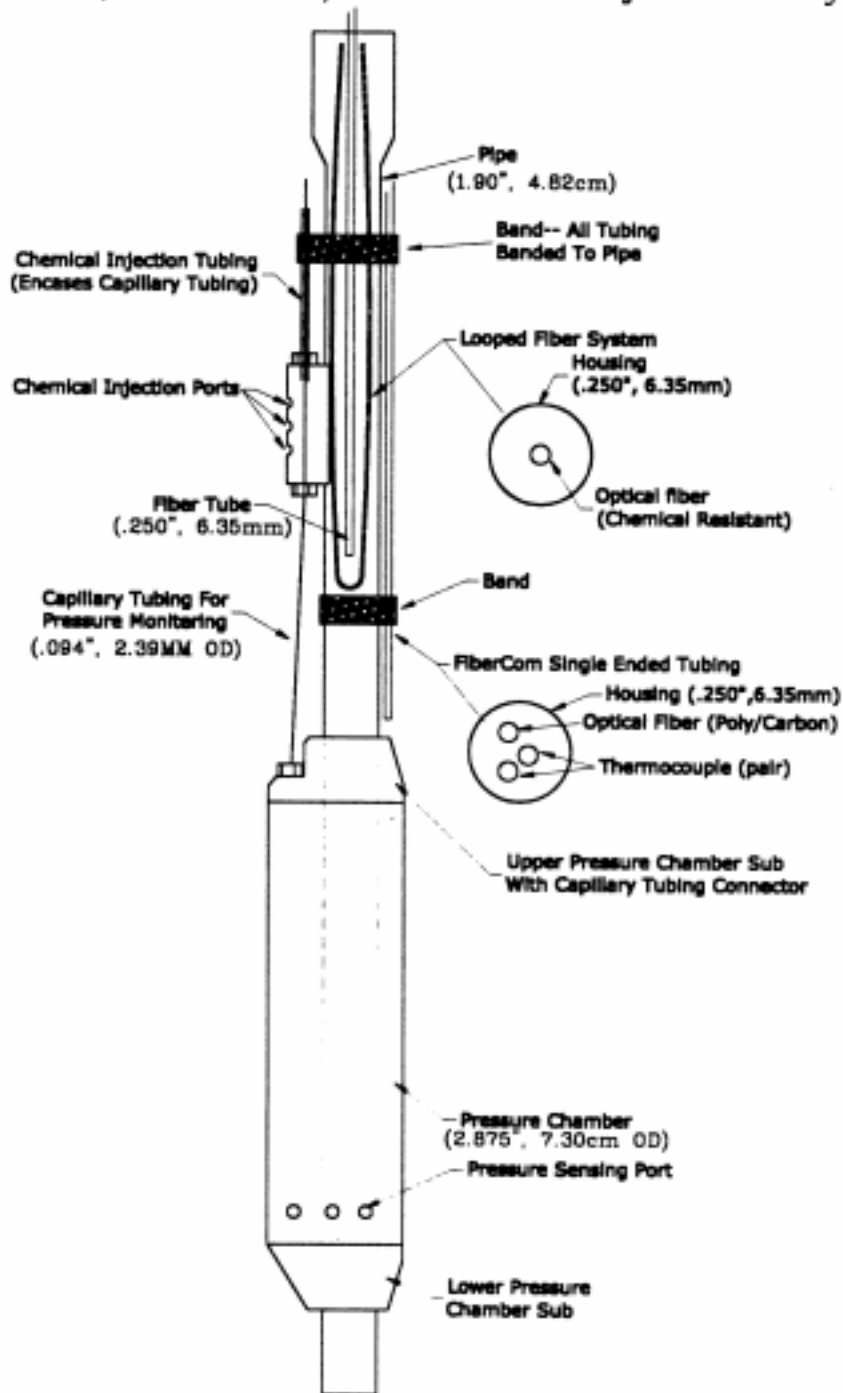


Figure 1. Not to scale design of installed hardware attached to the bottom joint of the 1.9" hangdown string. Two steel guards to protect the chemical injection head are not shown on this drawing. These are mounted vertically on either side of the injection head. Most of this hardware is mounted on the upper few feet of the bottom joint of the hangdown string.

Installation consisted of banding the cap tubing strings to the outside of the hangdown string with 0.75" wide steel bands. Three bands per joint of hangdown string were utilized. A total of 148 joints of hangdown string were installed. At the surface the 5 cap tubing strings were threaded through holes in the doughnut inside the tubing hanger and then through holes to the exterior of the tubing hanger. Bore through fittings provided a seal around the cap tubings. All cap tubings on the surface were routed to a stand where connections were made to a purge system, thermocouple and pressure transmitters, a data logger, optical fiber connectors, and the chemical pump. Power is provided by a solar panel and battery.

At 8:26 pm on July 9 compressed air was blown into the hangdown string to kick off the well. It was flowing on its own at or prior to 9:42 pm.

The installation process went smoothly with the exception of installing the tubing hanger. Getting the relatively stiff cap tubing strings through holes in the doughnut inside the hanger and through the top part of the hanger was relatively time consuming. Shortly after the tubing hanger was in place all components of the system were tested and all were operational.

The total length of the hangdown string was 4901' from the middle of the tubing hanger. The bottom of the optic fibers and the pressure chamber was at about 4872'. The thermocouple was installed at a depth of 4638' or 238' above the bottom of the optic fibers.

INITIAL DTS DATA ACQUISITION

Prior to kicking off the well on July 9, OTDR readings were obtained on both optic fibers to determine if they were still intact and to characterize their baseline light loss. Both fibers were also calibrated (Smithpeter et al., 1999). Once this was completed compressed air was blown into the hangdown string and a series of DTS logs were obtained with both optic fibers during the stimulation process. This marked the first time that the thermal aspects of kicking off a well were repeatedly recorded over a depth interval of 4872' in real time (Blackwell, et al. 1999 in press). A series of OTDR readings were again obtained on July 10 but unfortunately there was already measurable deterioration of the fibers ability to transmit light (Smithpeter et al., 1999). Sometime during the next month the single ended fiber broke at a depth of 3700'.

CALIBRATION TEMPERATURE LOGGING

A traversing temperature log was run inside the hangdown string by Pruett on the morning of July 10.

To check the calibration of Pruett's tool another Pruett log was run in well 45-14 a day after it was logged with Southern Methodist University's (SMU) memory tool. The Pruett temperatures were about 6 °F hotter than SMU's values. A correction factor of 2.8 °F was added to the thermocouple in the data logger as a result of the Pruett traversing log but it is now known that this has resulted in incorrectly high reported temperatures shown in Figures 2 and 3. However, for the purposes of this paper relative temperatures are adequate.

THERMOCOUPLE TEMPERATURE DATA

The thermocouple has provided continuous temperature data reported to one tenth of a degree Fahrenheit since it was installed. During routine flowing operations the thermocouple temperature swings over a 1 °F range over a period of a minute (Figure 2). When the well was shutin the thermocouple temperature was much more stable. This may be indicating that the temperature of the flowing well below the flash point is not constant. The thermocouple recorded the cooling history of one depth in the well over a period of 14 ½ days as it was shutin for a major plant outage (Figure 3).

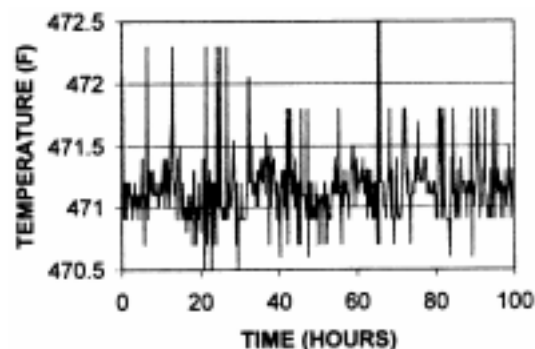


Figure 2. Details of thermocouple response over a period of 100 hours. A measurement is recorded every 15 minutes. Much of the variation seen in this figure can also be seen over a period of a minute or two.

The thermocouple has proven itself quite sensitive to small temperature changes as the temperature has short term declines of 1 to 2 °F following a purge of the pressure bomb with helium.

FUTURE RESEARCH PLANS

The downhole hardware is intended to remain in place until the next major field outage in 2002. Additional optical fibers will be installed in the cap tubings in 1999 and field tested for survivability.

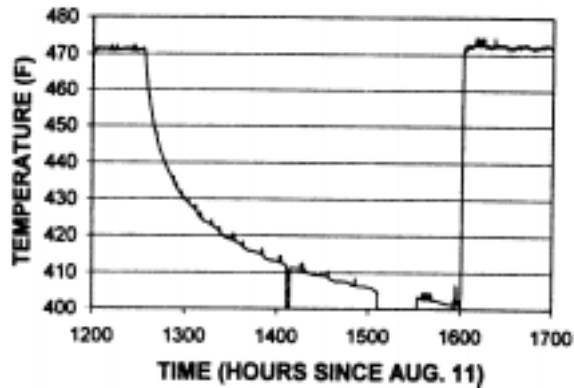


Figure 3. Long-term response of the thermocouple during a well shutdown of 14 ½ days. The true static temperature at the thermocouple depth of 4638' is approximately 320 °F. The regularly spaced small spikes are due to a glitch in the programming of the data logger. No data were collected between 1510 and 1550 hours.

CONCLUSIONS

A new generation wellbore/reservoir monitoring system was successfully fabricated and installed at a depth of 4900' in production well 74-7 at the Dixie Valley geothermal field. The system allows the well to be kicked off with compressed air, intermittent temperature measurements over the length of the hangdown string with both looped and single-ended optical fibers, continuous temperature and pressure monitoring at a single point below the flash point, carbonate scale inhibition, and the ability to run small diameter logging tools inside the hangdown string.

Unfortunately the optical fibers have either broken or degraded within days of installation but the thermocouple and downhole pressure chamber appear to be providing quality data.

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