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HIGH TEMPERATURE TESTING OF THE
EDCON BOREHOLE GRAVITY HOUSING SYSTEM
CONDUCTED AT LOS ALAMOS NATIONAL LABORATORIES

January 12 - 18, 1986

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INTRODUCTION

A series of tests were conducted from January 12 to 18, 1986 upon the EDCON borehole gravity meter (BHGM) high temperature sonde at the Los Alamos National Laboratory (LANL) Instrument Sonde Test Facility, Technical Area #33, Los Alamos, New Mexico. The tests were conducted to determine the suitability of this sonde for logging operations in the Department of Energy Salton Trough test well.

SONDE ASSEMBLY

FIGURE 1

SYSTEM DESCRIPTION

The BHGM sonde is a 5.25 inch outside diameter plated steel pressure tube approximately 11 feet long, designed to withstand pressures of 20,000 psi. A Dewar flask fits inside this pressure tube to isolate the BHGM instrumentation from the outside well temperatures. The design specifications for this unit were to provide at least 30 hours of operation at temperatures up to 400°F.

The bottom of the pressure tube is terminated by a "bullnose" plug which screws into the tube. O-rings provide leak protection about this join.

At the top of the pressure tube is a crossover sub designed to allow a standard Schlumberger compatible ten-pin cable head to be mated to the top of the tool. Several O-rings provide leak protection between the sub to pressure tube join, within the sub itself and between the cable head and the sub.

It is most likely that the logging at the Salton Trough well will take place from a U.S.G.S. owned high temperature wireline cable. The normal cable head used on this wireline is a Gearhart-Owens (G/O) type head. The system tested (Figure 1) was therefore designed to be compatible with a G/O type of head. A Schlumberger to G/O crossover sub was therefore connected to the top of the normal EDCON Schlumberger crossover sub. The top of the G/O Schlumberger crossover sub was then connected to a cable head manufactured by LANL via another sub, also manufactured by LANL. The field system would not require the LANL cable head and sub.

The G/O to Schlumberger crossover sub was not originally designed for high temperature operations. Prior to the test, this sub was upgraded by replacing low temperature wiring, solder, insulation, grease, and O-rings with materials rated to 300°C. The electrical isolation between conductors in this crossover was checked in a dry oven test to 260°C at EDCON in Denver prior to the LANL tests. Insulation resistance deteriorated to 20 megohms during the Denver tests. A point of concern was that dissimilar metals were used in the construction of this sub and differential expansion would occur at the high temperatures in the Salton Trough well, allowing some leaks to occur. This sub has been previously used in petroleum wells at temperatures up to 115°C and pressures up to 8000 PSI.

The many different connecting subs used to connect the LANL head to the BHGM sonde provide several possible failure points. An obvious way to minimize the number of potential failure points would be to manufacture a new cable head to attach directly to the BHGM sonde.

TESTING FACILITIES

The testing facilities were provided by LANL at Technical Area 33 (TA-33) in the main laboratory complex. Two test chambers were used.

The instrument Sonde Test Facility (ISTF) is a vertical autoclave capable of testing tools up to 8.5 m (28 feet) long and 152 mm (6 inch) diameter. A temperature of 275°C (527°F) is achievable at fluid pressures of 6000 psi (41.4 MP_a). Higher temperatures may be achieved at lower fluid pressures. An overhead workover tower provides cranes to assist the placing of the test tools in the autoclave. Seven conductors allow the internal sonde resistances to be monitored.

A National K Works environmental muffled oven, Model 65-156 is used for dry thermal testing of thermal protection systems. It operates to temperatures of 500°C (932°F) using a programmed controller. It accepts tools up to 3.6 m (12 ft) long and 152 mm (6 inch) diameter.

These test facilities are described by Dennis, et al, 1985.

TESTING PROCEDURE

The tests had a threefold purpose:

1. To check the pressure seal system under temperatures up to 300°C (572°F) and pressures up to 34.5 MP_a (5000 psi)
2. To check the electrical integrity of the system under these conditions
3. To check the Dewar flask behavior at these temperatures and determine an operating time for the complete BHGM system at these temperatures

The first two of the above items were tested in the vertical autoclave (ISTF). The third was tested in the dry thermal oven.

TABLE 1

Date 1-13-86

Time (MST)	Pressure (PSI)	Fluid Temperature (°C)	Heater Temperature (°C)
---------------	-------------------	---------------------------	----------------------------

1810	802	36	*58
1825	2300	54	274
1840	2750	73	292
1850	2712	85	296
1905	3975	106	290
1915	3741	118	278
1930	3728	132	286
1945	3653	150	288
2000	3684	162	300
2015	3643	177	**312
2020	3298	185	-
2037	3348	195	-
2045	3426	202	-
2050	3569	208	-
2120	3584	234	340
2130	3526	241	333
2145	3580	251	331
2150	3733	252	327
2155	4230	254	314
2200	4300	255	284
2213	4360	254	338
2235	4363	258	321
2330	4350	259	306
2400	4350	260	291

Date 1-14-86

1145	0	107	115
1200	0	100	81
1205	0	100	***95
1210	300	78	93
1213	600	76	93
1220	3200	80	96
1228	4350	82	98
1250	3500	85	102
1255	-	85	102
1258	800	85	102
1313	0	67	88
1318	0	64	85
1342	0	56	75

*electrical isolation good

**electrical isolation bad

***conductor isolation good

PRESSURE SONDE TEST 1

The sonde assembly shown in Figure 1 was lowered into the autoclave after raising it from a horizontal position. Bending of this assembly at the G/O crossover sub was noted and human strength was used to lessen this bending during the pick up. Table 1 shows the temperature and pressure record for this test. These records are shown graphically in Figures 2, 3, and 4. Figure 5 is a conversion graph to derive true autoclave pressures from the meter pressures shown in Figure 1.

A pressure drop of about 400 psi occurred at 8.25 hours. After ten hours, the pressure and temperature were steady at about 5000 psi and 260°C respectively. This state continued until the test was stopped at 12 hours.

The resistance between each of the seven conductors and ground was periodically checked during the test with a "meggermeter". These results are shown in Table 2.

TABLE 2

Time	Resistance
Up to 8.25	10 X
9.00	1-2 M X
9.75	.5 M X
12.00	.15 MX

The nature of the pressure drop and recovery suggested that water had passed an O-ring into a small cavity and had been prevented from going farther by another O-ring seal. Upon disassembling the system, the most likely place found for this to have happened was in the LANL to G/O crossover sub where the

O-rings had degraded and an amphenol electrical connector was cracked. Multiple small leaks noticed in the autoclave plumbing during the test were identified and repaired. The other seals and backup rings in the system looked good on inspection.

This test indicates that apart from the LANL to G/O connector sub failure, the system maintained its pressure seal at 5000 psi and 260°C. The electrical insulation was probably invaded by fluid in the LANL to G/O sub and no conclusions can be drawn about the electrical integrity of the other parts of the system.

TABLE 3
Date 1-15-86

Time (MST)	Pressure (PSI)	Fluid Temperature (°C)	Heater Temperature (°C)
1730	26	47	59
1748	486	60	255
1800	2316	76	295
1815	4382	97	323
1820	4392	107	*321
1830	3744	116	**241
1845	2108	125	191
1900	1120	127	170
1915	457	129	150
1930	181	129	145
1944	977	127	135
2000	416	127	133
2015	126	127	135
2030	-	125	130
2045	647	127	128
2115	301	122	125
2215	500	115	119

*electrical leak
**heaters off

PRESSURE SONDE TEST 2

The damaged O-rings and connectors identified during the first test were replaced, the system was assembled vertically to prevent stain on the G/O connector and then placed again in the autoclave.

Table 3 shows the time, temperature, and pressure records for this test. Upon reaching 50000 psi pressure and 107°C, the lines again became electrically shorted to ground. The system was then cooled, disassembled, and inspected. No water leaks or connection problems were found. Upon cooling, the electrical leaks disappear.

It was suspected that the G/O to Schlumberger crossover connection, being the only part of the system not already field proven in higher pressure and temperature conditions then experienced during this second test, was the likely source of electrical failure.

TABLE 4

Date 1-16-86 - Pressure Test 3

Time (MST)	Pressure (PSI)	Fluid Temperature (°C)	Heater Temperature (°C)
1035	0	68	*68
1045	2500	68	68
1050	3500	68	68
1052	4000	-	-
1055	4292	-	-
1345	0	-	**85
1350	21	67	85
1405	478	74	224
1415	1443	82	257
1430	3522	97	288
1445	4382	117	304
1448	4387	120	***308
1500	4091	130	232
1518	3017	137	188
1530	2691	140	173
1545	2326	140	162
1603	1931	139	152
1616	1667	139	147
1634	1323	137	143
1645	1131	137	141

*electrical isolation ok

**Pressure bled to start heater

***electrical shorts turn off heater

PRESSURE TEST 3

A connector was replaced in the G/O to Schlumberger crossover sub and the system assembled once more in the autoclave. Electrical resistance was good when the pressure was raised to 5010 psi at a temperature of 68°C. The pressure was then bled off and then increased with temperature until a pressure of about 5000 psi and a temperature of 120°C was reached. At this point all lines except one showed electrical shorts. The pressure and temperature were lowered and the system disassembled.

Pressure Tests 2 and 3 both showed electrical isolation resistance between conductors dropped rapidly with increasing temperature. This did not occur with increased pressure at low temperature. The relatively sudden drop in the resistance between conductors once the temperature is raised above 100°C suggests that some moisture may be turning to steam and providing electrical leakage paths.

The 7 (seven) pin connectors from the LANL to G/O crossover and the EDCON to G/O crossover were then placed in an air oven. The isolation resistances of the wires in these connectors began to degrade at 170°C and at 260°C were about 3 megohms. This does not explain the autoclave results as the air oven would have allowed the water vapor to dissipate from the connectors. Within the sonde, the pressure would rise within the isolated cavities containing the connectors, forcing water vapor into the connectors.

FIGURE 2

DEWAR FLASK TEST

The Dewar flask is used to isolate the BHGM and the downhole electronics from the high temperature well environment. This allows the electronic components to operate without failing due to heat and keeps the air surrounding the BHGM element below its thermostating temperature of approximately 125°C.

Since the thermostating oven and the electronics both dissipate heat which is trapped within the Dewar, internal fusible metal heat sinks are used to prevent the temperature within the Dewar from rising too rapidly. The design specifications for the Dewar system specified that operation should be possible in a 400° well environment for 30 hours. The highest temperature well logged to date was at 350°F. The internal Dewar temperature after 24 hours of operation was 104°C.

As the external temperature increases, the allowable time of operation will decrease. This test was run to estimate the allowable operation time at 300°C. The BHGM was not placed in the Dewar for insurance reasons, but the heat sinks were installed.

Figure 2 shows the temperature as a function of time for several positions inside and outside the Dewar. Figure 3 shows the position of these heat sensors.

PLACEMENT DIAGRAM OF HEAT SENSORS IN LANL AIR OVEN TEST

- ELECTRONICS INSIDE DEWAR FLASK
- BHGM COMPARTMENT INSIDE DEWAR FLASK
- ✕ AIR BETWEEN OVEN AND DEWAR FLASK WALL
- Δ DEWAR FLASK OUTER WALL
- INSIDE TOP PLUG
- TOP END, OUTSIDE

FIGURE 3

The thermocouple in the air outside the Dewar is the equivalent in this experiment of the well temperature. The BHGM thermistor and the electronic thermocouple are the temperatures which would be experienced by the electronics module and the BHGM element.

From these temperatures, it is possible to estimate the actual internal temperature after a certain immersion time with the BHGM inside the Dewar if we know the temperature history with the BHGM operating in the Dewar commencing at room temperature. From Appendix 1, the temperature after 10 hours operation at 300°C well temperatures should be about 96°C, measured in the electronics compartment of the Dewar. The temperature in the BHGM element compartment should, according to all other tests done with this equipment, be slightly lower.

CONCLUSIONS AND RECOMMENDATIONS

The results of these tests indicate that over short periods of time, the system tested provided a good pressure seal, apart from one failure in the crossover connector subs. Electrical leakage between the conductors is a problem above 100°. Dry heat tests on the downhole connectors show increasing leakage to about 3 megohms at 260°C. Apparently moisture is present either through minor seal leakage or from the assembly of the components that is causing these electrical leaks. The probability of these leaks occurring could be decreased by simplifying the system of crossover connecting subs and paying careful attention to drying the connectors thoroughly before assembly.

The Dewar test indicated that the downhole operation should be able to run conservatively for 10 hours before the temperature begins to cause

electronic component failures. The operating time may be extended by cooling the heat sinks to about 0°C before assembly. This runs the risk of introducing moisture to the system through condensation if the air humidity is high.

REFERENCES

"High Temperature Borehole Instrumentation", Dennis, B.R., Koezan, S.P., Stephani, E.L. Publication LA-10558-HDR, UC-666. Issued by Los Alamos National Laboratory, New Mexico, October 1985.

APPENDIX

Consider two cases:

Case (1): The Dewar flask, including heat sinks, is placed in an oven from which an amount of heat Q_1 enters the Dewar in time τ raising the internal temperature of the Dewar and contents by ΔT . Suppose the mass of the inside of the Dewar and the heatsinks is M_1 and they have an average specific heat of S_1 .

$$\text{Then } \Delta T_1 = \frac{Q_1}{M_1 S_1} = \frac{Q_1}{W_1} \quad (1)$$

Case (2): The Dewar flask with the heat sinks and the BHGM installed is at room temperature. The BHGM is turned on for a time τ during which it emits a quantity of heat Q_2 and raises the temperature of the Dewar and contents by ΔT^2 .

The mass of the inside of the Dewar and contents is now $M_1 + M_2$ and the average specific heat of the BHGM is S_2 .

$$\text{Then } \Delta T_2 = \frac{Q_2}{M_1 S_1 + M_2 S_2} \quad (2)$$

If the two cases are combined, i.e., the operating BHGM in the Dewar is immersed in an oven or well for time τ at the same external temperature as in case (1), the total heat introduced to the Dewar contents is Q where

$$Q = Q_1 + Q_2$$

We would like to calculate the change in temperature of the Dewar contents, ΔT , over time τ .

$$\Delta T = \frac{Q}{W_1 + W_2}$$

$$\text{i.e. } \Delta T = \frac{Q_1 + Q_2}{W_1 + W_2}$$

$$= \frac{W_1 (\Delta T_1 + \Delta T_2) + W_2 \Delta T_2}{(W_1 + W_2)} \quad -(3)$$

Actual values after 10 hours for ΔT_1 and ΔT_2 are 39°C and 65°C respectively.

To estimate the specific mass for Case (1) and Case (2):

Mass of Dewar inside wall ~ 7000 g.

Specific heat $\sim .1$ cal/g/ $^\circ\text{C}$

Mass of heat sinks ~ 40000 g

Specific heat $\sim .03$ cal/g/ $^\circ\text{C}$

Therefore $W_1 \sim 7000 \times .1 + 40000 \times .03 = 1900$ cal/ $^\circ\text{C}$.

Mass of BHGM $\sim$ 20,000 g

Specific heat $\sim$.2 cal/g/°C.

Therefore $W_2 \sim 20,000 \times .2 \sim 4000$ cal/°C.

Inserting values into equation (3) we have:

$$\Delta T = \frac{1900 (39 + 65) + 4000 \times 65}{1900 + 4000} = 77.6^\circ$$

i.e. after 10 hours in a well at 300°C the internal temperature of the Dewar flask should be about 77.6°C.