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Equipment Development Report

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Borehole-Fluid Sampling Tool

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of the University of California

LOS ALAMOS, NEW MEXICO 87545

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EQUIPMENT DEVELOPMENT REPORT

Borehole-Fluid Sampling Tool

by

J. R. Archuleta

C. F. Fink

J. Kurtenbach

ABSTRACT

This report discusses the design and development of a tool for collecting fluid samples from hot, deep geothermal boreholes. This tool has performed satisfactorily in the field at downhole temperatures of 200°C and pressures of 34.5 MPa (5000 psi). Assembly and operating instructions are included.

1. INTRODUCTION

Chemical analyses of fluid samples, taken at various depths in a geothermal borehole, are often useful in the investigation of geothermal reservoir properties. However, collecting fluid samples can be difficult at the high temperatures and pressures that exist in most geothermal boreholes. A tool to collect fluid samples must be able to open and close reliably under these extreme conditions.

Borehole-fluid sampling tools are available commercially, and several have been tested in the Los Alamos Scientific Laboratory's (LASL's) Hot Dry Rock Geothermal Energy Development Project. In these tests, it was found that the commercially available tools operated unsatisfactorily, principally because of the high-temperature ($\sim 200^{\circ}\text{C}$) environment. Therefore, LASL undertook the development of a new fluid sampling tool. Such a tool was successfully developed. The design and operational details of this tool as well as the results of field testing are reported herein.

2. DESIGN REQUIREMENTS

The design for the fluid sampling tool was to meet the following requirements.

1. Must be able to operate using only one electrical conductor of the logging cable plus the ground return.
2. Must be able to collect two samples at two different depths in the borehole (or two samples at one depth) using three conductors of the logging cable.
3. Must operate downhole at 200°C and 41 MPa (6000 psi) for 12-h durations.
4. Must be capable of being upgraded to operate at 275°C and 68.9 MPa (10 000 psi). (This requirement is to allow for future operation in still deeper and hotter boreholes.)
5. Fluid sample to be retained by a double seal, preferably metal-to-metal.
6. Surface readout should include:
 - a. motor current
 - b. valve position status.
7. Diameter of tool not to exceed 92 mm (3-5/8 in.).
8. Sample container to be of stainless steel material with a sample volume of about 0.25 liter.

3. OPERATING CHARACTERISTICS

The fluid sampling tool uses a DC permanent magnet motor and a planetary gearing system to rotate a shaft that can open or close a hand valve. The hand valve is mounted on the upper end-cap of the sample container and is normally closed, sealing the container. Check valves within the container allow inlet flow, but no reverse flow, providing a seal for the sample. Surface readouts during a sampling run provide the operator with the motor current, motor running time, and shaft revolutions. Shaft revolutions are monitored by a micro-switch that senses lobes on a cam attached to the motor output shaft. The switch is activated every 1/4 revolution. The upper and lower clutches, in conjunction with the micro-switch, augment operator control over the valve-opening sequence. The upper clutch allows the upper hand valve to be opened one revolution, whereas the lower clutch provides a two-revolution interval between opening the first valve and the second valve. The high-pressure bulkhead prevents water from damaging the cable head if the shaft seal fails. Characteristics of the motor and gearing system are:

1. maximum motor voltage, 115 Vdc
2. maximum current, 0.40 amp
3. speed reduction, 947:1

4. output shaft rotation, 8 rpm (no load)
5. normal rated torque, 21.5 N·m (190 in.-lb).

The valves are opened sequentially. The top valve opens first to obtain the first sample. In the sampling sequence, the first valve opens immediately with clockwise shaft rotation (viewed from the downhole end of the tool). After one clockwise shaft revolution, the upper clutch engages the container for the upper water sampler and the torque is transmitted to the lower clutch. Two revolutions of the lower clutch, a total of four shaft revolutions, open the lower valve one revolution, thereby obtaining the second sample. The hand valves are then closed by four counterclockwise shaft revolutions. Counterclockwise rotation is obtained by reversing the polarity of the motor voltage.

4. PERFORMANCE IN DOWNHOLE TESTS

All components, i.e., pressure vessels, seals, check valves, valves, bearings, motor, and switches, have been tested in a geothermal fluid-filled hole [200°C, 34.5 MPa (5000 psi)]. The pressure vessels and sample containers were designed to operate in a 275°C, 68.9-MPa (10 000-psi) environment. The vessel pressure rating is conservative; it is not a true collapse pressure but the pressure that generates yield stresses on the outer diameter wall.

The Bal-Seals used in the seal housing have been laboratory tested at high temperatures (225-275°C) and high pressures [34.5-41 MPa (5000-6000 psi)] for up to 13 days without failure. This type seal will be used in the sample containers upon upgrading to 275°C.

The DC permanent magnet motor was modified (as shown in Fig. A-4). Brush spring failures due to hydrogen embrittlement occurred after at most 5-min total operating time in the unmodified motor. A replacement spring was designed that lowered the stress level but developed the same brush-to-armature pressure. The replacement spring (Part No. 81Y210144) is made from stainless steel (17-7 PH, CH950). To upgrade the tool to 275°C requires thermal protection for the motor. A controlled environment enclosure has been designed for the motor which exploits the latent heat of fusion (in the phase change of a material, such as Cerrobend) as a heat sink.

The fluid sampling tool has been used to obtain fluid samples from EE-1 (Energy Extraction Hole No. 1, drilled in the Jemez Mountains in north-central New Mexico) at depths of 2957, 2896, and 2865 m using an armored 7-conductor

logging cable. Typical motor current and shaft revolutions, shown in Fig. A-11, are from a sampling sequence at 2957 m (9700 ft).

APPENDIX A

ASSEMBLY AND OPERATING INSTRUCTIONS

Assembly and operating instructions are included in Appendix A; detail drawings are enclosed in the back pocket.

1. ASSEMBLY

1.1. General

1. Use anti-seize tape (MIL-T-27730A) on pipe threads.
2. Use Krytox 240-AC lubricant on all seals, threads, and bearings except where noted.
3. O-rings are Viton except where noted.
4. Motor rework (as shown in Fig. A-4).
5. Use high-temperature solder and shrink tubing in all electrical connections.
6. Torque the set screw (Part 801) to 6.7-13.6 N·m (5-10 ft-lb). Apply a light coat of lubricant (Krytox 240-AC) to all threads before torquing.
7. The assembled tool is shown in Fig. A-1.

1.2. Motor and Shaft Assembly (see Fig. A-2)

1. Install 1/4-20 socket-head screw in the shaft (Part 502) using Loctite (A Viscosity, Class 10, MIL Specs 40083), and torque 13.6 N·m (10 ft-lb).
2. Press-fit bearing (ND 5302) on the shaft (Part 502).
 - a. Pack bearing with Krytox 240-AC lubricant.
 - b. Apply a light coat of lubricant to shaft.
3. Install Bal-Seal (505-206 GC) on shaft.
 - a. Open end of seal must face down; see Fig. A-2.
 - b. Fill seal cavity with Krytox 240-AC lubricant.
4. Lubricate shaft lightly and install it in the seal housing (Part 501).
5. Install bearing (SKF161605) and nut (Part 306); torque to 20-27 N·m (15-20 ft-lb).
6. Assemble switch mount, cam (Part 701), and coupling on shaft (Part 502).
7. Mount micro-switch and adjust to open and close every 1/4 revolution.

8. Assemble motor with coupling on motor mount (Part 204), (black motor lead as shown).

9. Attach motor assembly to seal housing (Part 501), leaving a 0.38-mm (0.015-in.) gap between shaft couplings(see Fig. A-3).

10. Motor rework (as shown in Fig. A-4).

1.3. High-Pressure Bulkhead and Cable-Head Sub (see Fig. A-5)

1. Install O-ring (2-231) in seal housing (Part 501). (Use Krytox 240-AC lubricant.)

2. Assemble seal housing (Part 501) and motor housing (Part 202); torque to 135 N·m (100 ft-lb) and install set screw (Part 801).

3. Assemble the male bulkhead (A10124) in the bulkhead feedthrough (Part 203), and connect electrical conductors to both sides of Part A10124.

4. Install O-ring in bulkhead feedthrough (Part 203). (Use Krytox 240-AC lubricant.)

5. Install the bulkhead feedthrough (Part 203) in the motor housing (Part 202).

6. Assemble motor housing (Part 202) to cable-head sub (Part 201); torque to 135 N·m (100 ft-lb) and install set screw (Part 801).

1.4. Clutch Assembly (see Fig. A-6)

1. Assemble the upper clutch (Part 405) according to Fig. A-6; use Loctite in threads indicated by .

2. Assemble lower clutch according to Fig. A-7; use Krytox 240-AC lubricant. To establish alignment marks, hold the lower clutch housing (Part 401) and rotate the lower clutch drive (Part 404) approximately two revolutions clockwise (viewed from downhole end of tool) until the clutch bottoms. Mark on bottom side of clutch as shown in Fig. A-7.

1.5. Sample Container Assembly (see drawing D-2)

1. Install Leechek valves in the check valve holder (Part 604) according to the procedure in the Lee Company handbook, and install Part 604 with the valve in the end-caps.

2. Assemble end-caps to cylinder, torque to 67 N·m (50 ft-lb), and install set screws (Part 801). (Do not lubricate O-rings.)

3. Install hand valves on the upper and lower fluid-sample can (Parts 101 and 102), and torque to 34 N·m (25 ft-lb) (hand valves reworked according to drawing D-7); close valves hand tight.

4. Assemble the seal housing (Part 501) and can housing (Part 303);

torque to 135 N·m (100 ft-lb) and install set screw (Part 801).

5. Install the upper clutch (Part 405) in the can housing (Part 303); rotate the upper clutch clockwise (viewed from downhole end of tool) until the clutch bottoms on the shaft's socket-head screws (1/4-20) (see Fig. A-8).

6. Install two 12-mm (0.5-in.) segments from a 5.33-mm cross section Viton O-ring in the upper fluid-sample can (Part 101), upper brake slots, and four 12-mm (0.50-in.) segments in the lower slots (see Fig. A-9). Assemble the upper fluid-sample can (Part 101) in the can housing (Part 303); adjust the number of O-ring segments to yield 20 N·m (15 ft-lb) of drag when rotating the sample can in the housing.

7. Orient the upper sample can (Part 101) so that the socket-head screws (1/4-20) engage the upper clutch (Part 405), as shown in Fig. A-9. Slide in the upper sample can, engaging the hand valve with the shaft forks (Part 502). (Motor shaft rotation may be required to allow engaging of hand valve.)

8. Install lower clutch (Parts 401, 402, 403, and 404) in the can housing (Part 303), engaging the pins of the upper fluid-sample can (Part 101). Rotate clutch to align marks.

9. Install O-ring segments in all grooves of the lower fluid-sample can (Part 102).

10. Slide the lower fluid-sample can in the can housing, engaging the hand valve handle in the lower clutch pins (Part 401).

11. Install the nose cone (Part 304); torque to 135 N·m (100 ft-lb) and install set screws (Part 801).

2. OPERATION

2.1. General

1. One electrical-conductor cable required for one sample and three conductors required to obtain two samples in one run.

2. Maximum tool diameter, 88.9 mm (3-1/2 in.).

3. Maximum external pressure capability, 68.9 MPa (10 000 psi).

4. Maximum temperature capability, 200°C.

2.2. Uphole Instrumentation

The wiring diagram is shown in Fig. A-10. With the red motor lead positive and the black lead negative, motor rotation is counterclockwise (viewed from downhole end of tool).

1. Counter-clockwise shaft rotation closes valve (viewed from downhole end of tool).
2. Clockwise rotation opens valve (viewed from downhole end of tool).
3. Surface Components
 - a. Power Supply (HP Model X)
 1. 125 Vdc
 2. 0.40-amp maximum
 - b. Recorder (HP Model Y)
 1. 2-channel
 2. Time marks

2.3. Uphole Diagnostics

1. Normal surface readout, shown in Fig. A-11.
2. Maximum current, 0.40 amps at 100 Vdc.
3. Motor rotation, about 8-5 rpm.
4. Micro-switch will go through 4 open-close cycles per shaft revolution.

2.4. Operation

Lower the tool to desired location and open the valves.

1. One clockwise motor revolution opens the first valve (4 switch open-close cycles).
2. After three clockwise revolutions, the second valve is engaged (12 switch open-close cycles).
3. At four total revolutions, the second valve has been opened one revolution.
4. Four counter-clockwise shaft revolutions (16 switch cycles) closes both valves. The upper valve is closed first.

After sample(s) is collected, bring tool to surface.

To retrieve sample:

1. Remove the nose cone (Part 304).
2. Using sample extractor tool (Part 702), remove sample containers.
3. Remove the container's end-cap to obtain sample.

2.5. Maintenance

1. Replace Viton O-ring after 12 h at 200°C or six temperature-pressure cycles.
2. Replace DC motor if the current fluctuates erratically during operation or armature resistance exceeds 500 ohms.

3. Retorque hand-valve body to end-cap after each downhole trip.
4. Adjust can (Part 101), drag torque after each sampling run.
5. Inspect check valves for proper operation.
6. After one year of service:
 - a. Disassemble shaft (Part 502) and inspect for corrosion.
 - b. Replace Bal-Seal.
 - c. Replace bearings NK5302 and SKF161605.
 - d. Replace hand valves.

Fig. A-1.
Fluid Sampler.

Fig. A-2.
Motor and shaft assembly.

Fig. A-3.

Gap between shaft couplings.

Fig. A-4.

Motor rework.

Fig. A-5.

High-pressure bulkhead and cable-head sub assembly.

Fig. A-6.

Upper clutch.

Fig. A-7.
Lower clutch.

Fig. A-8.
Installation of upper clutch.

Fig. A-9.

Lower sample container - installation.

Fig. A-10.

Water sampler wiring diagram.

Fig. A-11.

Typical motor current and shaft revolutions from downhole operation.

APPENDIX B

PARTS LIST

<u>Part No.</u>	<u>Description</u>
ND 5302	Bearing
SKF 161605	Bearing
505-206 GC	Bal Seal
2-231	O-Ring
M102M27	DC Permanent Magnet Motor (TRW Globe Motor)
RM D1098 145-1/4B	Hand Valve
M83723-02R1210N	Connector, Amphenol
101	Can, Upper Fluid Sample
102	Can, Lower Fluid Sample

<u>Part No.</u>	<u>Description</u>
201	Sub, Cable Head
202	Cylinder, Motor Housing
203	Bulkhead, Feedthrough
204	Motor Mount
303	Housing Can
304	Nose Cone
306	Nut
401	Lower Clutch Housing
402	Lower Clutch
403	Lower Clutch
404	Lower Clutch Drive
405	Upper Clutch
501	Housing, Seal
502	Shaft
604	Holder, Check Valve
701	Cam
702	Tool, Sample Extractor
703	Bracket
704	Valve, Hand
705	Coupling
800	Set Screw (10-32UNF)
801	Set Screw (1/4-28)

1.315

1.250

3/8 NPT
(REMOVE BURRS)

.600 WRENCH
FLATS

.675 DIA.

.3750 REAMED DIA.

.3755

1.06

FLATS
1

.500

(CHECK VALVE
HOLDER) (604)

MAT'L = 303 SST
MAKE (2)

1/4-28 UNF SET-SCREW
AT ASSEMBLY AS REQ'D
(DO NOT BREAK THRU)

C	PH	ADDED SOCKET HEAD SCREWS TO 101 CAN	8/11	NO K&S		
B	GOO	REVISED 101 & 102 ADDED GOA DELETED ASSY 100 WAS SHEET 1	10 13 76	CZL		
A	GOO	ORIGINAL ISSUE				
REVISION LETTER	CLASS REVISION	REVISIONS	DATE	CHANGED BY	CHECKED BY	APPROVED BY
Los Alamos scientific laboratory of the University of California SACRAMENTO, CALIFORNIA 95834 An International Research and Development Program			CLASSIFICATION OF DRAWING: J			
			PART: J TITLE BLOCK: J			
			TITLE			
			DOUBLE WATER SAMPLER 270 CC EACH			
TOLERANCES UNLESS OTHERWISE NOTED FINISH FRACTIONAL DECIMAL ANGULAR 12.5 1/32 .0005 .05°						
DESIGNED BY FINK DATE 7-28-76 GROUP Q22 DRAWN BY CZL DATE 7/24/76						
ORIGINATED CHECKED DRAWN MAG. DIM. APPROVED JAKE RELEASED			NO. REQD. SHEET NO. 6 SCALE 1/1 TOTAL SHEETS 81Y210123D-6			

PART NUMBER	QUANTITY	UNIT	DESCRIPTION

701 Cam - MAT'L SST 303

702 Scale 1/2
SAMPLE EXTRACTOR
MAT'L Brass or Mild Steel

703 Bracket - MAT'L ALUMINUM

704 TELEDYNE VALVE
Part No. D1098
Model No. 145-1/8

ORIGINAL ISSUE		DATE		CHANGED BY		CHECKED BY		APPROVED BY	
CLASSIFICATION OR DRAWING		PART		TITLE BLOCK		TITLE		TITLE	
los alamos scientific laboratory of the University of California 1015 Y-12, Santa Fe, New Mexico 87505		U		U		Water Sampler			
TOLERANCES UNLESS OTHERWISE NOTED FRACTIONAL DECIMAL ANGULAR 125 1/32 .005 .05		NO REQ							
ORIGINATOR	Jake	DATE		GROUP					
DRAWN	M.T.H. 7-21-76-4								
CHECKED									
PROF. ENGR									
APPROVED									
RELEASED									
SCALE	1/2	TOTAL SHEETS	7	DRAWING NO.	81Y210123	SHEET NO.	D-7

(104) MATL = 304 SST

NOTE: BREAK ALL SHARP EDGES
.010 ± 45° U.O.N.

A		ORIGINAL ISSUE		DATE		CHANGED BY		CHECKED BY		APPROVED BY	
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TOLERANCES - UNLESS OTHERWISE NOTED

FRACTIONAL	DECIMAL	ANGULAR
1/16 ± .002	± .001	± .0049

SIGNATURE	DATE	GROUP
ARCHULETA	2-14-75	Q-26
GRAY	2/4/75	
CHECKED		
FOU. SEAL		
APPROVED		
RE-ASSED		

CLASSIFICATION OF DRAWING:	
PART: 1	TITLE BLOCK: 1
TITLE	
<p>WATER SAMPLER (RUPTURE DISK)</p>	
NO. REQD.	
SCALE	1 = 1
TOTAL SHEETS	1
DRAWING NO.	81Y210073
CHECK NO.	D-1

PART NUMBER	QUANTITY	DESCRIPTION

(501) MAT'L = 303 SST

(502) MAT'L = 303 SST
BREAK SHARP EDGES 1/64

A		ORIGINAL ISSUE							
REVISION	CLASS	DATE	CHANGED BY	CHECKED BY	APPROVED BY				
LETTER	REVIEW								
LOS ALAMOS SCIENTIFIC LABORATORY of the University of California LOS ALAMOS, NEW MEXICO 87545						CLASSIFICATION OF DRAWING: U PART: U TITLE BLOCK: U TITLE: WATER SAMPLER			
TOLERANCES UNLESS OTHERWISE NOTED FINISH FRACTIONAL DECIMAL ANGULAR 12.5 1/32 1.009 .05°									
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APPROVED									
RELEASED									
SCALE: 1/4" = 1" TOTAL SHEETS: 1 DRAWING NO: 81Y210123						SHEET NO: 1 OF 1			

PART NUMBER	QUANTITY	UNIT	DESCRIPTION

A		ORIGINAL ISSUE		DATE		CHANGED BY		CHECKED BY		APPROVED BY	
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los alamos scientific laboratory		of the University of California		TITLE		WATER SAMPLER		NO REQ			
TOLERANCES UNLESS OTHERWISE NOTED		FROM: FRACTIONAL DECIMAL ANGULAR		125		1/32		.005		0.5°	
DRAWN		C. J. Smith		DATE		10/8/76		GROUP		D-326	
CHECKED											
PROJ. ENGR											
APPROVED											
RELEASED											
SCALE		TOTAL SHEETS		DRAWING NO.		81Y210123		SHEET NO.		D-4	

BILL OF MATERIAL			
PART NUMBER	QUANTITY	UNIT	DESCRIPTION

NOSE CONE (304) ALUM

CAN HOUSING

(303) MAT'L = SHELBY TUBING 3 1/2 D.D. x .250 WALL

BREAK ALL SHARP EDGES
.015 x 45° U.O.N.

B	Q20	ITEM 303, ADDED 1/2 DIA. ADDED SLOTS	14	12/16			
A	Q20	ORIGINAL ISSUE					
REVISION	CLASS	REVISION	DATE	CHANGED BY	CHECKED BY	APPROVED BY	
CLASSIFICATION OF DRAWING			PART U TITLE BLOCK U				
los alamos scientific laboratory of the University of California			DOUBLE WATER SAMPLER				
TOLERANCES UNLESS OTHERWISE NOTED FINISH FRACTIONAL DECIMAL ANGULAR 125 1/32 .005 .05°			NO REQ				
ORIGINATED	ARCHIVISTA	1-28-76	Q-22				
DRAWN	CF	1/28/76					
CHECKED							
PROJ. ENGR.							
APPROVED							
RELEASED							
SCALE	TOTAL SHEETS	DRAWING NO	SHEET NO				
1/16	1	81Y210123D-3	3				

A		ORIGINAL ISSUE							
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TOLERANCES UNLESS OTHERWISE NOTED: FINISH FRACTIONAL DECIMAL ANGULAR 125 ± .005 ± .005 ± .05									
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	ARCHER	1276	2-22						
DRAWN	C.F.L.	1/27/76							
CHECKED									
PROJ ENG				SCALE TOTAL DASHING NO SHEET NO 1/4 — 81Y210123D-2					
APPROVED									
RELEASED

MOTOR MOUNT (204) MAT'L=SS 303

FEEDTHRU (203) MAT'L = SST

BILL OF MATERIAL			
PART NUMBER	QUANTITY	UNIT	DESCRIPTION

1. CLOSE VALVES HAND TIGHT (SNUG).
2. ASSEMBLE 101 IN ITEM 303 TO ALLOW CLUTCH ITEM 405 TO TURN 1 REV. BEFORE TURNING CAN. (ALIGN MARKS)
3. PREWIND 401 CCW BEFORE ASSY. (ALIGN MARKS)

SECTION A-A

- TURN 1 REVOLUTION TO OPEN SAMPLE #1
TURN 5 (TOTAL) REVOLUTIONS TO OPEN SAMPLE #2
NOTE: ADJUST MICROSWITCH TO OPEN AND CLOSE EVERY 1/4 REV.
ADJUST SLIP CLUTCH (401) TO ALLOW 2 FULL TURNS BEFORE ENGAGING VALVE HANDLE.
ADJUST 405 TO ALLOW 1 TURN ON VALVE BEFORE TURNING SAMPLE

B 600 REVISED & REDRAWN		Q-13 978	CZ-4
A 600 ORIGINAL ISSUE		DATE	CHANGED BY
REVISIONS		DATE	CHANGED BY
CLASSIFICATION OR DRAWING U		TITLE	
PART U		TITLE BLOCK U	
TITLE		WATER SAMPLER	
270 CC EACH		NO REQ	
TOLERANCES UNLESS OTHERWISE NOTED: FRACTIONAL DECIMAL ANGLES 125 1/32 .005 .05		ORIGINATOR	
DRAWN		DATE	
CHECKED		GROUP	
PMO: ENR		SCALE	
APPROVED		TOTAL SHEETS	
RELEASED		DRAWING NO	
1/1		7 81Y210123 D-1	