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Equipment Development Report

Downhole Fluid Injector

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CONTENTS

ABSTRACT	1
1. INTRODUCTION	1
2. DESIGN PARAMETERS	2
3. PERFORMANCE IN DOWNHOLE TESTS	3
APPENDIX A: ASSEMBLY AND OPERATING INSTRUCTIONS	3
APPENDIX B: PARTS LIST	12

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EQUIPMENT DEVELOPMENT REPORT
DOWNHOLE FLUID INJECTOR

by

J. R. Archuleta
C. F. Fink
J. Kurtenbach

ABSTRACT

This report describes the development, design, fabrication, and operation of a tool used for injecting a discrete quantity of fluid (e.g. a dye) at a desired location within a hot geothermal borehole. Assembly and operating instructions are included.

1. INTRODUCTION

Certain flow tests of a manmade geothermal reservoir, under the Los Alamos Scientific Laboratory's (LASL's) Hot Dry Rock Geothermal Energy Development Project, required the injection of a carefully metered quantity of sodium fluorescein dye, as a tracer, into a fluid-filled borehole. The tool employed was developed at LASL. It will inject a calibrated volume of a selected fluid (dye, acid, etc.) into a wellbore at a prescribed location. The device is called a Downhole Fluid Injector (or colloquially, "pill pusher").

The fluid to be injected is contained in a cylindrical reservoir located at the lower end of the tool. The bottom of the reservoir is sealed by a piston, which also acts as a wiper during injection. The upper end-cap of the container incorporates discharge ports and flapper-type check valves that allow flow out of the container during ejection but prevent loss of the contained fluid while the tool is being lowered to the prescribed borehole location. Pressure equalization of the reservoir allows use of a thin-wall cylinder for the container. The latching system holds the reservoir cylinder and the piston and rod assembly together until the fluid is discharged. The release mechanism, which unlatches the container, is actuated by a motor-driven mechanical actuator. The cylinder drops over the rod and piston, discharging fluid through the orifices at the

upper end-cap of the container. The axial velocity of the cylinder is controlled by the wiper O-ring drag and by metering of the fluid flow through the discharge orifice. The descent of the cylinder is halted by the rod and piston, thereby loading the cable and giving a positive indication of cylinder release. These fluid injector tools have been designed for charges of 0.0075, 0.011, and 0.038 m³ (2 , 3-1/8 , and 10 gal), using a common release mechanism.

2. DESIGN PARAMETERS

Technical Data Summary

Length: 3.2 m (126 in.)

Weight: 63.5 kg (140 lb)

Working Temperature Rating: up to 200°C

Pressure Rating: 68.9 MPa (10 000 psi)

Maximum Diameter and Capacity:	92 mm (3-5/8 in.)	0.0075 m ³ (2 gal)
	102 mm (4 in.)	0.011 m ³ (3-1/8 gal)
	152 mm (6 in.)	0.038 m ³ (10 gal)

Power Requirements: 125 Vdc at 300 mA maximum

Cable Requirements: one independent electrical conductor (sheath return)

Motor: 1/50 hp dc, permanent-magnet type

The pressure rating is conservative; it is not a true collapse pressure but the pressure that generates yield stresses on the internal wall (i.d.) of the tube. The pressure vessel consists of two pieces: one section is an adapter (sub) to the cable head, and the other houses the motor and mechanical actuator.

The dc high-temperature motor, modified as shown in Fig. A-12, develops 21.0 N·m (186 in.-lb) torque through a planetary gear reduction system. The torque is transmitted through a multi-jawed coupling to the mechanical actuator, which converts it to thrust. The mechanical actuator comprises a ball nut and 19-mm-diam, 12.7-mm lead screw. The actuator is considered rigidly supported (fixed) by a pair of spaced bearings at one end and simply supported at the seal area. The column buckling load is 66.7 kN (15 000 lb); the maximum operational load developed by the actuator is 9.3 kN (2100 lb). The ball bearing screw and nut are lubricated with Krytox 240 AC to provide satisfactory service at 200°C.

The actuator shaft is redundantly sealed at its exit from the motor compartment and is hydraulically balanced by sealing of the lower end of the piston at the balance cylinder. The actuator shaft serves two functions. It unlatches

the locking mechanism and provides a 76-mm (3-in.) unseating displacement of the reservoir cylinder. During the unlatching sequence, the locking disk on the actuator shaft is displaced downward with outward actuator travel, allowing the reservoir cam to force the four steel balls off the locking ring (see Fig. A-10). If the weight of the reservoir cylinder is not sufficient to cam the steel balls, additional actuator travel will apply a force on the reservoir's upper end-cap through the four 6.4-mm (1/4-in.) rods, thereby driving the reservoir cam down and dislodging the four locking balls. The downward reservoir movement will unseat the lower piston O-ring, allowing the reservoir cylinder to fall downhole. The balls are confined within the tool by the retaining shield.

3. PERFORMANCE IN DOWNHOLE TESTS

The fluid injector tool has been used in a geothermal fluid-filled hole (EE-1, for Energy Extraction Hole No. 1) at 200°C and 34.5 MPa (5000 psi) in several tool development tests and for dye solution release in residence time distribution studies. As a result of the early tool development tests, check valves were added at the discharge ports to prevent dilution of the contained fluid during tool insertion.

Structural strength has been verified by tests. The tool was assembled without fluid in its reservoir, installed in a fixture, and the outer cylinder released. This severe condition, not typical of normal operation, develops maximum loads in the rod and piston assembly. Post-test examination indicated that no permanent yielding occurred in the loaded components.

APPENDIX A

ASSEMBLY AND OPERATING INSTRUCTIONS

1. ASSEMBLY

1.1. General

1. The assembled tool is shown in Fig. A-1.
2. Use Krytox 240-AC lubricant on all seals, threads, and bearings except where noted.
3. Use Viton O-rings except where noted.
4. Motor rework as shown in Fig. A-12.

5. Use high-temperature solder and shrink tubing in all electrical connections.

6. Flag indicates use of Loctite "A" viscosity, Class 10, MIL Spec 40083.

7. Torque the 1/4-28 set screws to 1.4-2.8 N·m (1-2 ft-lb).

1.2. Mechanical Actuator Assembly (see Fig. A-2)

1. Lightly lubricate the shaft of the -903 screw and install the -103 bearing and 110-203 spacer.

2. Install the 9/16 nut on the 101-903 shaft, torque to 40 N·m (30 ft-lb), and install set screw.

3. Install the -102 coupling and -800 set screw.

4. Slip the 101-304 nut over -903 screw.

5. Assemble the -104 ball nut on 101-903 screw and install the 1/8-in. roll pin. (Note: Ball nut threads must face downhole.)

6. Assemble the -203 rod to -902 actuator shaft and install -800 set screw.

7. Assemble -902 shaft to the -104 ball nut; torque to 40 N·m (30 ft-lb).

8. Lubricate the internal diameter of the 110-202 bearing housing with Krytox 240 AC and press-fit the -103 bearings in the housing.

9. Install the -304 nut, torque to 40 N·m (30 ft-lb), and install the -800 set screw.

10. Assemble the motor with coupling on the 110-202 bearing housing, leaving a 0.38-mm (0.015-in.) gap between shaft couplings. (See Fig. A-3.) (Black motor lead as shown in Fig. A-1.)

1.3. Seal Housing (see Fig. A-4)

1. Open end of seal must face down.

2. Apply a light film of lubricant to the 145-201 seal housing and install the -107 seal. (Note: Fill the seal cavity with Krytox 240-AC lubricant.)

3. Install the -202 nut. Torque to 20-30 N·m (15-20 ft-lb).

4. Install the -101 O-ring in the 110-201 actuator housing.

5. Assemble the 145-201 seal housing to the 110-201 housing, torque to 135 N·m (100 ft-lb), and install the -800 set screw. (Note: Seals in the -201 housing must face down.) (See Fig. A-4.)

1.4. Balance Cylinder and Actuator Shaft (see Fig. A-5)

1. Insert the mechanical actuator assembly into the 110-201 housing

and into the 145-201 assembly such that the shaft protrudes through. (Note: DO NOT engage the 110-202 locking lug on the bearing housing.)

2. Install the four -405 rods in the -402 locking shaft. Torque the 1/4-20 nuts to 20 N·m (15 ft-lb). (Note: Adjust rod length as shown in Fig. A-6.)

3. Assemble the -402 shaft and the 145-203 rod. Torque to 40 N·m (30 ft-lb) and install the -800 set screw.

4. Assemble the -204 locking cylinder to the 145-201 seal housing. Torque to 135 N·m (100 ft-lb) and install the -800 set screw.

5. Install the -107 seal and the 145-202 nut in the -205 balance cylinder. (Note: Open end of seal must face up. Fill seal cavity with Krytox 240-AC lubricant.) (See Fig. A-5.)

6. Insert the -405 rods and the -402 shaft in the -205 cylinder.

7. Assemble the -205 cylinder and the -204 locking cylinder. Torque to 135 N·m (100 ft-lb) and install the -800 set screw. (Note: Allow mechanical actuator to rotate during assembly of -204 locking cylinder and -205 cylinder.)

8. Assemble the -301 shield to the -204 cylinder.

9. Align the 110-202 locking lug on the bearing housing and the 110-201 housing slot, and insert the actuator and motor assembly into the 110-201 housing. (See Fig. A-7.)

10. Install O-ring in the 121-903 sub and assemble on the 110-201 actuator housing. Torque to 135 N·m (100 ft-lb) and install the -800 set screw.

1.5. Reservoir Assembly (see Fig. A-8)

1. Insert the -605 rod through the -604 upper end-cap and attach to the -205 balance cylinder. Torque to 70 N·m (50 ft-lb) and install the -800 set screw.

2. Assemble the -603 piston to the -605 rod. Torque to 70 N·m (50 ft-lb) and install the -800 set screw.

3. Assemble the -602 cylinder and the -601 nose cone. Torque to 70 N·m (50 ft-lb) and install the -800 set screw.

4. Install the cylindrical reservoir (-602 and -601) over the -603 piston and attach to the -604 upper end-cap. Torque to 70 N·m (50 ft-lb) and install the -800 set screw.

1.6. Latching (see Fig. A-9)

1. Retract the mechanical actuator leaving a 0.38-mm to 3.80-mm (0.015-in. to 0.15-in.) gap between the 145-201 seal housing and the -402 locking shaft. (See Fig. A-8.)

2. Align the hole in the -301 shield with the cam hole in the -602 reservoir and the -204 locking cylinder.

3. Insert four 15.88-mm (0.625-in.) steel balls into the locking slot. (See Fig. A-10a.)

4. Torque the -301 shield to 135 N·m (100 ft-lb) and install the -800 set screw.

2. OPERATION

2.1. Uphole Instrumentation

The wiring diagram is shown in Fig. A-11. With the red motor lead positive and the black lead negative, motor rotation is counterclockwise (viewed from downhole end of tool). Clockwise shaft rotation extends the actuator; counterclockwise shaft rotation retracts the actuator.

The motor rework is shown in Fig. A-12. Equipment requirements include a 125-Vdc, 400-amp power supply and two-channel recorder.

2.2. Operation

Typical motor current from a downhole operation is shown in Fig. A-13.

Hang the assembled and latched tool vertically over the borehole and fill through the discharge orifices, then lower tool to desired location.

To inject fluid, turn switch to release position, thereby causing: Clockwise motor shaft rotation (viewed from downhole end of tool), which will extend the actuator, releasing the balls. (About 5 s of motor running time are required to unlatch.) The actuator engages the reservoir discharge head after 10-s total running time and will extend to full stroke after about 20 s. Upon injection of the fluid (about 15-20 s), a slight shock will be transmitted uphole through the cable, indicating that the cylinder has stopped descending. Actuator bottoming is determined by sharp current rise. The last step is to recover the tool.

2.3. Maintenance

1. Replace Viton O-rings 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. After one year of service:

a) Disassemble the mechanical actuator and inspect the 145-203 rod and -402 shaft for corrosion.

- b) Replace the Bal-Seals.
- c) Lubricate the ball nut and bearings.
- d) Inspect the -605 rod for cracks.

Fig. A-1.
Assembled tool.

Fig. A-2.
Assembly of mechanical actuator.

Fig. A-3.

Motor coupling assembly showing gap between couplings.

Fig. A-4.

Seal housing assembly.

Fig. A-5.

Balance cylinder and actuator shaft.

Fig. A-6.
Push rod installation.

Fig. A-7.
Orientation of locking lug and slot.

Fig. A-8.
Reservoir assembly.

Fig. A-9.
Latching mechanism.

Fig. A-10.
Unlatching sequence.

Fig. A-11.
Wiring diagram.

Fig. A-12.
High-temperature dc motor rework.

Fig. A-13.
Typical motor current from a downhole operation.

APPENDIX B

PARTS LIST

<u>Part No.</u>	<u>Description</u>
81Y210144	Torsion Spring
81Y210145-101	Viton O-ring, No. 2-228
81Y210145-102	Multi-jaw Coupling
81Y210145-103	Ball Bearing, NDH 55602
81Y210145-104	Ball Nut
81Y210145-105	Nut, 7/16-20 UNF
81Y210145-106	Roll Pin, 1/8-in.-diam, 1-in.-long
81Y210145-107	Bal Seal, Part No. 505-206-GC
81Y210145-108	Viton O-ring, 2-340
81Y210145-109	Viton O-ring, 2-332
81Y210145-110	Viton O-ring, 2-239
81Y210145-201	Seal Housing
81Y210145-202	Nut
81Y210145-203	Rod, actuator
81Y210145-204	Cylinder, locking
81Y210145-205	Cylinder, balance
81Y210145-301	Retaining Shield
81Y210145-402	Shaft, locking
81Y210145-405	Push Rod
81Y210145-601	Nose Cone
81Y210145-602	Cylinder, reservoir
81Y210145-603	Piston, reservoir
81Y210145-604	Upper End-Cap, reservoir
81Y210145-605	Rod, reservoir
81Y210145-800	Set Screw, 1/4-28 UNF
81Y210101-304	Nut, bearing retainer
81Y210101-903	Lead Screw
81Y210101-902	Cylinder Mechanical Actuator Shaft
81Y210110-202	Bearing Housing
81Y210110-201	Mechanical Actuator Housing
81Y210110-203	Spacer
81Y210121-905	Motor Flange Rework
81Y210121-903	Cable-Head Adapter Sub

BILL OF MATERIAL			
PART NUMBER	QUANTITY	PER	DESCRIPTION

605 SST

C	ADD DIMENSIONS	2-4	UT 12	
B	ADDED VALVE	5-10	CFNK CF	EFF
Los Alamos Scientific Laboratory UNIVERSITY OF CALIFORNIA LOS ALAMOS, NEW MEXICO 87545 TEL: 505/667-1000 FAX: 505/667-1001 E-MAIL: lsalamos@lanl.gov WWW: http://www.lanl.gov				
DRAWN: C.F. 4/1/77 G-6 CHECKED: [] APPROVED: [] RELEASED: []				
SCALE: 1/1 TOTAL SHEETS: 1 DRAWING NO: 81Y210145 D-6 SHEET NO: 1				

BILL OF MATERIAL			
ITEM	QUANTITY	PER	DESCRIPTION

501 MAT'L - ALUM

502 MAT'L - ALUM

SETSCREW 1/4-28UNF x 1/4 LG
WITH RUBBER CUSHION.
SETSCREW & GROOVE
180° APART.

503 MAT'L - ALUM
MAKE TWO PIECES

- GENERAL NOTES: (UNLESS OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES.
 2. BREAK ALL SHARP EDGES.
 3. USE 1/16" ALL TAPPED HOLES TO MAJOR DIAMETER.
 4. USE 1/16" x .030 DEEP ALL DRILLED HOLES.
 5. DIMENSIONING & POSITIONAL TOLERANCES PER ASME Y14.5-1975.
 6. WELDING SYMBOLS PER AWS A5.1-1968.
 7. SURFACE TEXTURE PER ASA B46.1-1962.

A		ORIGINAL ISSUE	
REVISION	CLASS	DATE	CHANGED/CHECKED/ APPROVED
		CLASSIFICATION OF DRAWING TYPE: TITLE: GEOPHONE HOUSING FOR 3 1/8, 10 GALLON PILL PUSHER	
TOLERANCES: UNLESS OTHERWISE NOTED FINISH: FRACTIONAL DECIMAL ANGULAR 125 1/12 1/16 1/8 1/4 1/2 3/4 1 1 1/2 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100		NO. REQD. SCALE: 1/1" = 1" TOTAL SHEETS: 1 DRAWING NO: 81V210145 SHEET: D-5	
ORIGINATED	DATE	GROUP	
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CHECKED	DATE	GROUP	
APPROVED	DATE	GROUP	
RELEASED	DATE	GROUP	

BILL OF MATERIAL				DESCRIPTION
PART NUMBER	QUANTITY	UNIT	REMARKS

401 MAT'L = ALUMINUM BAR ROUND

403 MAT'L = ALUMINUM BAR ROUND

402 MAT'L = STAINLESS STEEL

405 MAT'L 1/4" STEEL ROD
4 REQ'D

404 MAT'L = ALUMINUM TUBE

- GENERAL NOTES: (UNLESS OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES.
 2. BREAK ALL SHARP EDGES.
 3. CH 82° ALL TAPPED HOLES TO MAJOR DIAMETER.
 4. CH 82° & .030 DEEP ALL DRILLED HOLES.
 5. DIMENSIONS & POSITIONAL TOLERANCES PER ANSI Y14.5-1975.
 6. WELDING SYMBOLS PER AWS Y22.3-1969.
 7. SURFACE TEXTURE PER ASA B46.1-1962.

B 100 ADD 405 REVISE 303 9/19 Hus 13		ORIGINAL ISSUE		REVISIONS	
REVISION	CLASS	DATE	CHANGED BY	CHECKED BY	APPROVED BY
los alamos scientific laboratory of the University of California		CLASSIFICATION OF DRAWING			
PART		TITLE BLOCK			
TITLE		PILL PUSHER			
NO REQ					
SCALE		TOTAL SHEETS			
1/1		21X210145 D 4			

BILL OF MATERIAL				DESCRIPTION
PART NUMBER	QUANTITY	RECD	PER

301 MAT'L = MILD STEEL

303 MAT'L = MILD STEEL

302 MAT'L = ALUMINUM BAR ROUND

304 MAT'L = ALUMINUM BAR ROUND

- GENERAL NOTES: (UNLESS OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES.
 2. BREAK ALL SHARP EDGES.
 3. CSK 82° ALL TAPPED HOLES TO MAJOR DIAMETER.
 4. CSK 82° & 80° DEEP ALL DRILLED HOLES.
 5. DIMENSIONS & POSITIONAL TOLERANCES PER ANSI Y14.5-1973.
 6. WELDING SYMBOLS PER AWS A5.1-1969.
 7. SURFACE TEXTURE PER ASA B46.1-1962.

3	REV	CHANGE DIMENSIONS	10-4	MJM		
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TOLERANCES UNLESS OTHERWISE NOTED						
FINISH FRACTIONAL DECIMAL ANGULAR						
12.5 1.0 12.5 12.5 12.5						
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1/1	1	81V210-145	D 3			

BILL OF MATERIAL			
PART NUMBER	NUMBER REQD.	PER	DESCRIPTION

201 MAT'L = 4340 H.T. RC. 35/40

202 MAT'L = STEEL
MAKE THREE

203 MAT'L = 4340 H.T. RC. 35/40

204 MAT'L = STAINLESS STEEL

205 MAT'L = STAINLESS STEEL

- GENERAL NOTES: (EXCEPT OTHERWISE NOTED)
1. ALL DIMENSIONS IN INCHES.
 2. BREAK ALL SHARP EDGES.
 3. CH #2 ALL TAPPED HOLES TO MAJOR DIAMETER.
 4. CH #2 & #3 DEEP ALL DRILLED HOLES.
 5. DIMENSIONING & POSITIONAL TOLERANCES PER ANSI Y14.5-1973.
 6. WELDING SYMBOLS PER ANSI Y14.5-1973.
 7. SURFACE TEXTURE PER ASA B46.1-1962.

REVISE DIMENSIONS		10-4	1977	174		
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ORIGINATED	SIGNATURE	DATE	GROUP	NO REQD.		
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SCALE	TOTAL SHEETS	DRAWING NO.	SHEET NO.			
1/1	1	81Y210145	D 2			

BILL OF MATERIAL				DESCRIPTION
PART NUMBER	QUANTITY	PER

B	30	CHANGE PART NUMBERS	10-5	10-4	9/1
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REVISION		DATE: 10-5-77			
APPROVED BY: DMC		DATE: 10-5-77			
TITLE: PILL PUSHER		DRAWING NO: 81Y210145D-1			
SCALE: 1/1		TOTAL SHEETS: 7			
ORIGINATED: 10-5-77		DRAWN: 10-5-77			
CHECKED: 10-5-77		APPROVED: 10-5-77			
RELEASER: 10-5-77		NO REQ			