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TITLE: ARMORED INSTRUMENTATION CABLE FOR GEOTHERMAL WELL LOGGING

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ARMORED INSTRUMENTATION CABLE FOR GEOTHERMAL WELL LOGGING

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ABSTRACT

Multiconductor armored well-logging cable is used extensively by the oil and natural gas industry to lower various instruments used to measure the geological and geophysical parameters into deep wellbores. Advanced technology in oil-well drilling makes it possible to achieve borehole depths of 9 km (30 000 ft). The higher temperatures in these deeper boreholes demand advancements in the design and manufacturing of wireline cable and in the electrical insulating and armoring materials used as integral componets. The recent increase of interest in acquiring new, clean alternate energy resources has placed emphasis on exploration of formerly untested geothermal energy systems including hot dry rock. If geothermal energy is proved an abundant economic resource, drilling temperatures approaching and exceeding 300°C will become commonplace. The adaptation of teflons as electrical insulating material permitted use of armored cable in geothermal wellbores where temperatures are slightly in excess of 200°C, and where the concentrations of corrosive minerals and gases are high. Teflon materials presently used in wireline cables, however, are not capable of continuous operation at the anticipated higher temperatures.

INTRODUCTION

Our research in materials, equipment, and instrument development is being done to meet the needs of the DOE geothermal programs. The materials development programs are funded by the DOE under the Department of Geothermal Energy. This research is coordinated with needs in other DOE geothermal programs to develop hardware of greatest overall utility and to avoid duplication. Much of the research in the areas of materials, equipment, and instrument components are cooperative efforts with the Sandia National Laboratories to ensure the most efficient expenditure of available funds.

The high-temperature and high fluid-pressure in geothermal wells pose severe limitations on wireline-logging instruments and on the armored instrumentation cable.

Teflon FEP was for many years the only melt-processable thermal plastic that could be used as an insulation material in wireline cables to meet logging criteria at temperatures as high as 235°C. In the early seventies, several teflon fluorocarbon resins were developed for high-temperature work. Some successful insulating materials used for well-logging wirelines include: (1) Tefzel (ETFE) - a copolymer of ethylene and tetrafluoroethylene; (2) TFE - tetrafluoroethylene; (3) FEP - fluorinated ethylene propylene; and (4) PFA - perfluorazlkoxy. These materials were tested by Dupont, the primary supplier, for general applications as electric-wire insulation. Table I is a summary of the tests conducted by Dupont.

Testing of these materials for use in wireline applications has been done primarily by companies that manufacture the armored cable. The results of such testing is usually proprietary. Some testing with small pieces from standard cable has been done by others. The primary objective of most tests was to determine the tensile strength and the insulation resistance as a function of pressure and temperature.

One leading armored cable manufacturer subjected single conductor armored logging cables that included combinations of FEP, Tefzel, and PFA as conductor insulation and jackets to controlled tension and temperature tests. The tests measured resultant torque and elongation of the cables as the tension and temperature were varied. A summarized evaluation of the test indicates that Tefzel is a satisfactory material for temperatures up to 240°C and that the PFA Teflon is satisfactory up to 295°C. FEP Teflon has a continuous temperature rating for use in wirelines up to 235°C, but has lower tensile strength than either PFA or Tefzel. The TFE material has excellent insulation resistance vs temperature properties. This material, however, can not be extruded over the copper conductor. It must be applied in a tape wrap which is susceptible to leakage at high hydrostatic fluid pressures encountered in deep wells.

HIGH-TEMPERATURE CABLE CANDIDATES FOR FENTON HILL

The Phase II Energy Extraction System at the Fenton Hill Test Site will consist of two wellbores drilled to a depth of about 4570 m (15 000 ft) and then connected by a series of hydraulic-induced fractures. The first borehole (EE-2), completed in May of 1980, reached a depth of 4633 m (15 200 ft) of which approximately 3960 m (13 000 ft) is in Precambrian granitic rock. Starting at a depth of approximately 2930 m (9600 ft), the borehole was inclined up to 35° from vertical. Bottom-hole temperature in EE-2 is 320°C. The EE-3 borehole was then drilled to a depth of 4236 m (13 900 ft). Its inclined part is positioned directly over the EE-2 wellbore with a vertical separation of about 450 m (1500 ft) between them.

It was imperative that the geophysical parameters of the Phase II fracture system be carefully monitored, and that its dimensions and orientation be measured in order to optimize fluid-flow and heat-transfer properties. To ensure the development of a usable, armored instrument cable for both near-term and continued use in the Phase II System, the Laboratory initiated a cable test program. A series of tests were designed to evaluate the electrical and mechanical characteristics of prototype cables purchased by the Los Alamos National Laboratory for use on the Hot Dry Rock Geothermal Project.

In order to characterize the EE-2 borehole environment (for programmatic planning of the near-term hydraulic fracturing experiments), an interim high-temperature cable was purchased to provide needed wellbore surveys. This cable was made by the Vector Cable Company and is similar to a cable procured by the USGS and used in hot boreholes with reportedly good performance. This cable is constructed in the "standard" 7-conductor, 7/16-in.-diam, contrahelical, armored, well-logging package, but uses a TFE Teflon tape-wrapped outer jacket (rated at 320°C). The jacket is used both as a strengthening member for the core and as an armor bedding (Fig. 1). The cable was first subjected to a "soak test" in the EE-2 borehole to obtain preliminary information on the electrical performance. In the soak test the cable was run into the wellbore to a depth of 3048 m (10 000 ft) where the temperature is 202°C. The IR of each conductor to armor was measured over a period of 6 h. Test results are shown in Table II. Conductor No. 7 (center conductor) showed a noticeable IR degradation during this initial soak test.

Following the soak test, this cable was used for the temperature surveys made in EE-2. The three conductors not used for the temperature measurements were monitored throughout the logging runs (see Table III). It is significant that the center conductor recovered from the low IR measurement and no degradation has been observed in subsequent borehole surveys. When the cable was retrieved from the wellbore, the IR recovered to its original status, and no observable damage or degradation could be determined. Thus, the cable appears to perform well for short residence time in the high-temperature environment.

The primary consideration for the Phase II program was a need for a coaxial cable that can operate satisfactorily when subjected both to a hot water borehole with temperatures up to 320°C and to hydrostatic pressures up to 58.6 MPa (8500 psi). Prototype cable samples were purchased from several manufacturers for the engineering evaluation. The coaxial cable component sample consists of a center conductor, dielectric insulation, shield, and outer jacket. The samples from manufacturers differed in geometry, physical dimensions, type of insulation material, conductor material, etc. Each sample purchased was 304.8 m (1000 ft) long. The selection was based on material and design considerations as stated by the cable manufacturers.

A promising new development in sintering techniques has made possible the manufacture of continuous long lengths of TFE insulated cable. A 304.8-m (1000-ft) sample of a TFE coax cable was procured as part of the engineering evaluation. Preliminary temperature/pressure tests gave excellent results (Fig. 2). A 6-m (20-ft) length of this TFE insulated coaxial cable was subjected to a cyclic temperature/pressure test in water at the Laboratory's cable test facility. The cable was taken to a temperature of 325°C and a pressure of 15.2 MPa (2200 psi) and held for a period of 6.8 h. The autoclave was allowed to cool to

50°C. Several temperature cycles up to 325°C were implemented. The temperature was then raised to 350°C at a pressure of 17.2 MPa (2500 psi) and held for 2.8 h.

No significant changes in attenuation or signal response occurred during the test. No changes were seen in the TDR traces at 325°C, and only a slight change was seen after almost 3 h at 350°C. Many of the electrical characteristics changed very little throughout the test, except for a reduction in the resistance between the center conductor and shield. The Hi-Pot resistance changed from an initial 22 MΩ at 500 V at ambient conditions to 160 KΩ at 50 V at 350°C and 17.2 MPa (2500 psi) at the end of the test. Insulating resistance measurements are summarized in Table IV.

CONCLUSION

The development of new high-temperature materials components and sensors has paved the way for upgrading required downhole instrument systems for the Hot Dry Rock Phase II measurements. The development of the TFE Teflon electrical insulation for armored cable fabrication promises the capability of surveying geothermal boreholes where temperatures exceed 300°C. The ultimate instrumentation systems are by no means just around the corner. The TFE Teflon insulation provides a high-temperature capability, but problems such as eventual fluid intrusion, reduction of IR with temperature and time, and other limitations may still arise. It is important that research continue in such areas as fiber optics and metal sheathed conductors to still further improve geothermal measurements.

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TABLE I. Typical property data, teflon fluorocarbon resin.

Properties		FEP	Tefzel	PFA	TFE
Tensile Strength	Bars (psi)	214 (3100)	448 (6500)	296 (4300)	275 (4000)
Elongation	%	330	150	300	600
Continuous Service Temp	°C (°F)	205 (400)	150 (302)	260 (500)	260 (500)
Dielectric Constant	10^6 Hz	2.1	2.6	2.1	2.1
Dissipation Factor	10^6 Hz	0.0003	0.005	0.0002	0.0002
Water Absorption	%	0.01	0.02	0.03	0.01
Chemical Resistance	Penetration Properties	Excellent	Excellent	Excellent	Excellent
Long Term Aging		NA	200°C 2000 H	285°C 2500	NA

TABLE II. High-temperature cable soak test for EE-2, Depth = 3048 m (10 000 ft), EMP = 202°C.

			Lead Resistance To Armor				
	1	2	3	4	5	6	7
Control At Ambient	4000	4000	4000	4000	4000	4000	4000
Time At 10 000 Ft							
0 H	450	200	175	150	175	225	90
2 H	150	90	100	75	80	85	48
4 H	100	70	70	65	65	75	22
6 H	90	65	65	65	65	70	4

TABLE III. High-temperature cable IR measurements, temperature log for EE-2 dated 8/12/80.

			Lead Resistance To Armor MΩ		
Time	Depth	Temp °C	#5	#6	#7
12:24	3000	94	1000	1000	20
14:23	14 000	290	5	5	
14:40	15 000	314	3	3	2
14:50	14 145	316	2	2	1.5
16:43	9900	200	20	20	20

TABLE IV. TFE insulated coax test results.

	Ambient 7/28/81	Initial	Test Conditions 7 Hours @	3 Hours @
Test Parameters				
Temp (°C)	19	325	325	350
Press (psi)	200	2000	2000	2500
DC Resistance MΩ				
Center Cond/Shield	>20 M	>20 M	>20 M	4 M
Shield/Ground	>20 M	>20 M	10 M	----------
Magger Resistance				
Center Cond/Shield	>20 M/500 V	9 M/500 V	6 M/500 V	160 K/50 V
Shield/Ground	200 K/500 V	200 K/500 V	1.8 M/100 V	----------

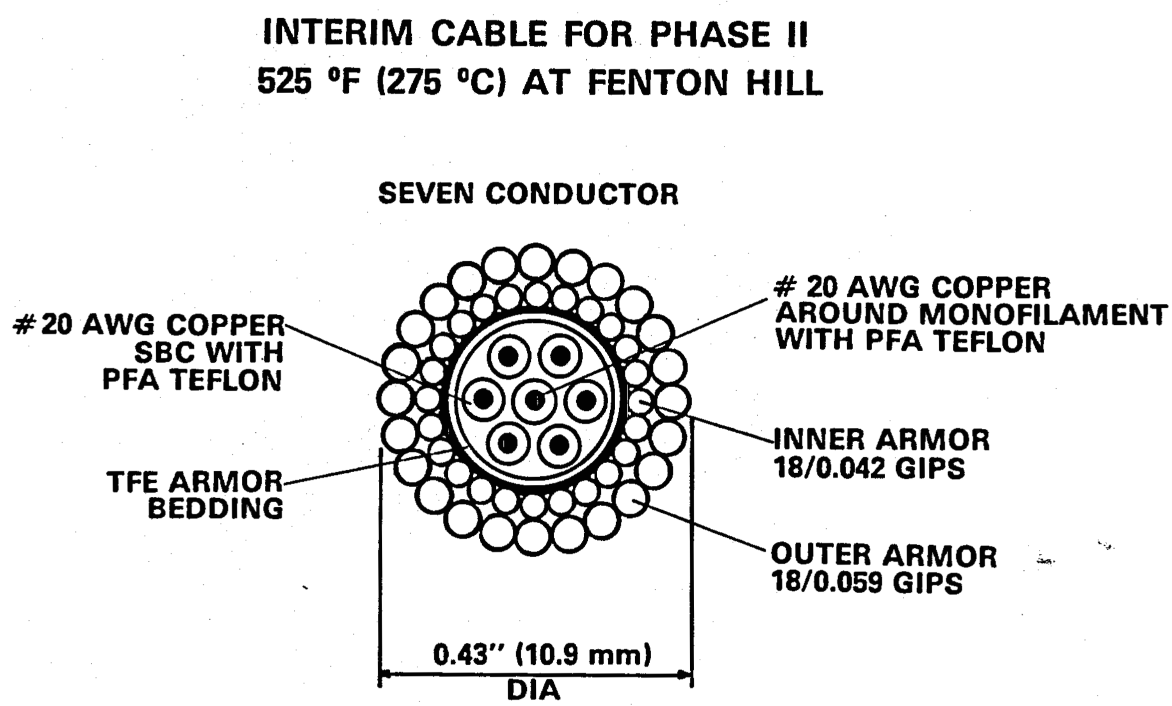
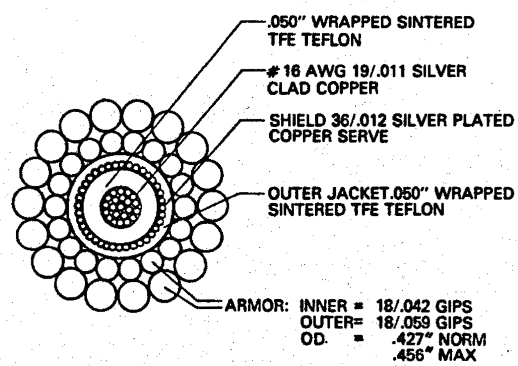


Figure 1. Interim cable for Phase II at Fenton Hill.



ELECTRICAL:

DC RESISTANCE — CENTER CONDUCTOR . . . 4.0 ohms/MFT
SERVE SHIELD . . . . 2.5 ohms/MFT

CAPACITANCE . . . . 37 pf/ft

CHARACTERISTIC IMP AT 100 KHZ . . . . 50 ohms

ATTENUATION AT 100 KHZ . . . . 1.2 DB/MFT OR LESS

VOLTAGE RATING . . . . 1000 VRMS

MECHANICAL:

BREAKING STRENGTH . . . . 16,000 LBS

TEMP RATING . . . . NORMAL 600 °F
SHORT TERM 630 °F

Figure 2. High-temperature coax cable.