CABLE SELECTION PROCESS FOR SUBMERSIBLE OIL WELL PUMPS

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INTRODUCTION

Whenever large volumes of oil-well fluid have to be lifted, the submersible pump-motor system is the most logical artificial lift system to use. The submersible pump will operate efficiently above 300 barrels per day. The submersible pumping system is composed of the motor, seal, pump, and other hardware, as well as a long length of power cable. The most obvious unique feature of a submersible system is its geometry to fit a narrow hole and its reliability to last under adverse environmental conditions without convenient access for repair or inspection. Generally speaking, cables are neither the most complex element in a submersible pumping system nor the most delicate or susceptible to damage. The majority of cables in application today last many years with a minimum of repair requirement. Nevertheless when cable damage occurs, it becomes a significant problem. Anytime cable damage occurs, the whole system has to be shut down, pump and motor pulled, and a very simple repair done, with again a feeling of having to go through all that trouble and cost for a seemingly insignificant reason. Because of this feature of the application, the process of selection of the submersible power cable needs to be understood.

Historically, cables were initially made by manufacturers of general purpose cables for mining, communication, heavy machinery, and building industries. The manufacture of cables has been divorced from the oil-field production equipment industry and out of touch with the oil-field requirements. There has been little guidance, specialized technical know-how, or business incentive for the cable manufacturers to carry on intensive research and development on cable improvements for oil-well application. Submersible equipment manufacturers began to test and specify oil-resistant power cable construction in the late 1950's. In the 1960's the manufacturers of Centrilift submersible oil well pump equipment contracted their corporate research center to undertake long-term development of submersible power cables more specifically suited to oil-well applications. Through their initiative and that of the centralized research team at Borg-Warner in cooperation with key material suppliers as well as cable manufacturers, and with field testing by most major oil companies, new cables are being developed and an extensive amount of knowledge is being generated about cable requirements, material performance, field handling practices, splicing, etc. The purpose of this paper is to provide those using or considering the use of submersible pumping systems information about the selection of cable and thus, in an objective manner, to enhance the reliability of submersible-pump systems and encourage their application.

DEFINING THE ENVIRONMENT

Before any selection of electrical cable for an oil well, there must be sufficient information about well conditions. Throughout the world, there are reservoirs of petroleum that fall into general categories of being hot, deep, acid, gassy, oil rich, sandy, etc. This information provides an initial starting point for the determination of whether a high-temperature or low-temperature cable is needed and whether special attention should be given to armor, corrosion, etc. Such general information about reservoirs of oil fields can be obtained through local governments, geological survey centers, field operators, academic institutions, etc.

For a cable to perform reliably in an oil well, it must carry current properly and resist attack by the environment. Environmental conditions which damage a cable (not in order of priority) are as follows.

- Fluid temperature
- Fluid pressure
- Gas pressure
- Chemical composition of the gas and fluid
- Chemical constituents of well treatment

Cable problems and repairs are infrequent and insignificant when the environment to which they are subjected is mild, if the cable is properly selected and its installation is properly done. For example, in 1968 in Oklahoma at Northwest Camp Deese oil field for well No. 64 the selection of the submersible equipment was obviously carried out with forethought and care, which resulted in a run of 4-1/2 years without any problems. However, only 400 run days without having to pull the submersible system for any reason which stops production is the average considering all wells. Cables are subject to damage when they are exposed to an extremely high temperature or chemical corrosion environment. This damage is progressive. All synthetic and all natural organic materials will deteriorate with time in a temperature and chemical environment. As temperature goes up, the deterioration rate increases.

Fluid pressure and gas pressure have been found to be far more critical to cable performance than expected. Pressure, just as temperature, exaggerates any chemical effect. At high pressure, gases which normally do not permeate a cable jacketing will permeate in time. At higher pressure and temperature, those same gases will permeate even faster. At the same time, rubber materials commercially expounded as oil resistant lose their oil resistance at higher pressures. They lose it even faster at high temperature along with high pressure.

The principal element in the effect of oil-well environment on a submersible power cable is the effect on its jacketing and insulation. Rules of thumb, shown in Table 1, have been used in the past to predict the accelerated deterioration rate of organic material. These rules of thumb, even though they are generalizations, are useful.

TABLE 1 -RULES OF THUMB IN OIL WELL SUBMERSIBLE CABLE SELECTION

ALL
cables and splices deteriorate with use in time!
but . . .
at rates depending on
CONDITIONS + MATERIALS

When exposed to water, minerals and inorganics
PLASTICS - Unaffected
RUBBERS - Permeable

When exposed to oil
PLASTICS - Only soften (unless highly plasticized)
RUBBERS - Most soften
Some harden at elevated temperatures

When exposed to gases
PLASTICS - Permeable under pressure
RUBBERS - Highly permeable

When BRIEFLY OVERHEATED
PLASTICS - Melt
RUBBER - Okay

When BRIEFLY OVERHEATED after prolonged oil exposure
PLASTICS - Melt quicker
RUBBERS - Deform and crack.

LONG EXPOSURE to moderate heat
PLASTICS - Slowly deform or embrittle.
RUBBERS - Harden and crack.

CABLES FOR MODERATE CONDITION, TYPICAL WELLS

The majority of oil wells today, perhaps somewhere around 85 percent, are of moderate well conditions. That is, they are neither very hot, very gassy, extremely deviated, nor have high pressure or an unusual chemical composition. For example, a well whose bottom-hole temperature does not exceed 150°F and pressure is less than 2000 psi can be treated as a moderate condition. For these wells, the process of cable selection is very straightforward. Reliability of performance over a number of years is dependent only on common sense, proper handling, and proper splicing techniques.

In the selection of the cable, consideration of handling features has to be given only to the extreme cold temperature conditions at the surface; in this case one must keep in mind that most thermoplastic cables at temperatures approaching -40^{0}F are subject to cracking unless handled very slowly and with unusual care. The selection of a cable for the typical condition well of mild environmental conditions does require a commitment to proper splicing. In advance one must know to what other cables the selected one will have to be spliced, and if sufficient adhesion can be expected.

Table 2 describes the currently available commercial cables by the materials from which their jacketing and insulation are made, and points out their features and limitations. The maximum temperature limit is set by the melting, degradation, or other physical failure of the materials. However, the maximum use temperature may be much lower depending on the effects of air, water, oil, long exposure time, and resistance heating.

TABLE 2—OIL WELL CABLES IN USE TODAY

CONSTRUCTION				Max.* Temp. Limit	QUALIFICATIONS
Configuration	Jacket	Insulation	Armor		
Flat	Lead	EPR Rubber	Metal	325°F	Lead splice to rubber difficult to make. Easily damaged, costly. Insulation has poor oil resistance
Flat	Nitrile	EPR Rubber	Metal	250°F	Nitrile age hardens after prolonged use. Insulation has poor oil resistance.
Flat	None	Crosslinked Polyethylene	None	190°F	Crosslinked polyethylene softens and creeps at elevated temps and has poor oil resistance
Flat	None	PVC	None	200°F	PVC embrittles with age and has poor oil resistance
Flat	Neoprene	EPR Rubber	Metal	250°F	Neoprene has fair oil resistance and the EPR rubber insulation is poor in oil.
Round	Nitrile	Copolymer Polypropylene	Metal	230°F	Insulation limits use temp. because of its lower heat distortion temp.
Round	Epichlorohydrin rubber	Homopolymer Polypropylene	Metal	275°F	Insulation increases cables use temp. but decreases low temp. usefulness.
Round	Acrylate rubber	EPR rubber	Metal	300°F	Limited by fair oil resistance and poor water resistance. Acrylate rubber hardens on aging.
Round	Nitrile	Crosslinked Polyethylene	None	190°F	Nitrile age hardens and crosslinked polyethylene has poor oil resistance.
Round	Polyethylene	Copolymer Polypropylene	None	150°F	Jacket has low heat distortion point and only fair oil resistance.
Round	EPR Rubber	EPR Rubber	Metal	325°F	Only fair oil resistance of jacket and insulation
Round	Nitrile	EPR Rubber	Metal	250°F	Nitrile hardens on aging. EPR rubber is not oil resistant

* This does not discount the temperature limit for effect of air, water, oil, long exposure time and resistance heating.

CABLES FOR SPECIAL CASE, SEVERE WELL CONDITIONS

It is becoming apparent that as oil becomes scarcer, the conditions under which it will be retrieved can be expected to become more severe. Currently used cable materials have evolved by a process of elimination, and confidence has been gained by experience. However, there is an increasing demand for longer life and higher reliability cables with new applications in wells of greater depth and higher temperature. Therefore, we have to look at materials in more detail for the selection process. The following sections describe methods which have been developed for selecting cable materials.

Chemical Aging

Chemical environment, including temperature and pressure, of an oil well has the greatest effect on cable life; it changes tensile properties, volume (through swelling), and hardness. These properties can be easily measured in the laboratory for selection prior to field application.

Figure 1 shows a typical result for an experimental nitrile rubber aged in air at various temperatures. The failure criterion was arbitrarily set as when the product of tensile strength (psi) times elongation (percent) falls below 10,000. Thus, a sample with 100 mph-psi tensile strength and 100-percent elongation would be very weak and soft like putty compared to a sample with 10,000 -psi tensile strength and 1-percent elongation, which would be very stiff and hard and would crack going over a sheave. Both samples would have little utility as a cable material. The important point learned is that about three months of aging is required to differentiate between the tensile properties of potential cable materials, rather than the normal 70-hour aging done under ASTM methods.

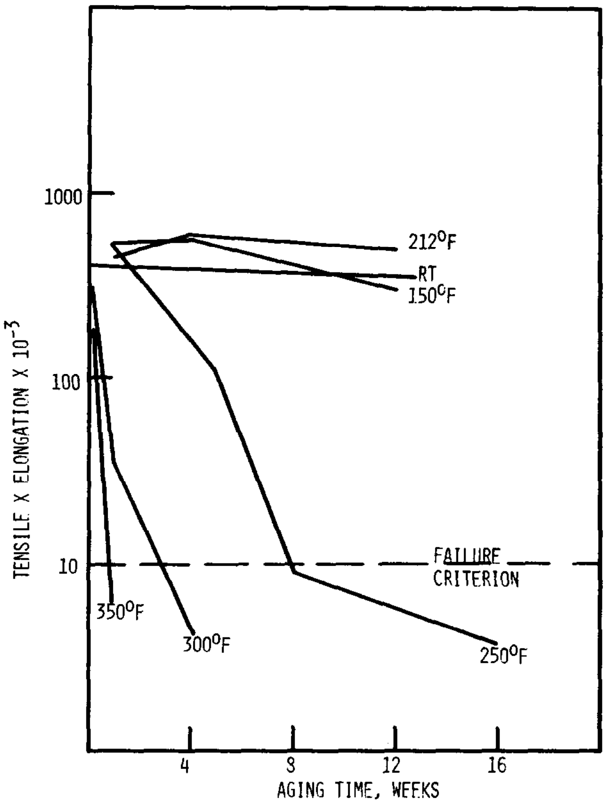

FIG. 1—EFFECT OF NITRILE AGING IN AIR

Estimating the Effect of Temperature

When the downhole temperature of the fluid is expected to result in a borderline cable application, it is imperative that the temperature gradient be calculated, i.e., the temperature inside the cable be estimated to include the resistance heating effect of the electrical power it carries. The means to calculate this temperature rise in various cable constructions can be developed using classical heat-transfer techniques or other techniques such as empirical simulations or finite-element analysis.

With our own computer modeling, a temperature increase of 100°F from ambient is not impossible, but 50°F is a more common expectation for resistance heating. Thus with wells below 150°F, resistance heating can generally be included in cable selection. The 150° to 200°F range is a gray area and electrical sizing may be the best way to eliminate excess resistance heating. However, above 200°F fluid temperature, full consideration of resistance heating is required for proper design of the cable insulation and jacketing.

Gas Pressure

The effects of gas are primarily those of permeation; these effects become damaging during the depressurization of the cable when it is withdrawn from the well. Presently effects can be determined only experimentally by subjective testing either in the laboratory in a pressure bomb, or in actual field conditions. In the laboratory measurements have been made under 2000 psi in methane and 4000 psi in nitrogen at elevated temperatures. In some cases material samples are placed in the working fluid which, in turn, is placed in the bomb after dimensional measurements have been taken. For actual cable samples, epoxy end caps are used to prevent seepage at the cut ends. After 7 days the samples are removed and by means of differential weight measurements in air and water, volume change is calculated. The rate of pressurization and depressurization is, of course, significant in such laboratory measurements. Thus, for a more realistic measurement, actual field conditions must be used in the final test.

Test Cells

Actual well conditions can have combinations of air, oil, water, and other ingredients, as well as the cable-construction variables that make accurate prediction of material performance difficult. Where feasible by the criteria of cost, a test-cell procedure provides on-the-site controlled testing of possible oil-well cable components. It is in fact no more than testing cables and materials in an actual condition attached to the bottom of the motor prior to a final selection and commitment.

The various cable samples, armored, unarmored, insulation, etc. are usually capped with an epoxy at both ends to prevent seepage of the well fluid into the samples through their ends. The slabs and film are placed in a cage of wire mesh. Measurements are made before and after exposure to well conditions. Diameter measurements of the cables are taken before and after exposure. The slabs and plastic film are tested for the usual physical properties. A gas analysis could also be performed for those cables that retain expansion caused by the gas. Temperature may be recorded using a temperature capsule.

Thus with careful analysis, the test cell provides a new dimension in cable specification which can be considered along with the physical, chemical, and electrical specifications of cables.

DISCUSSION

There is considerable activity in developing new cables of greater reliability, or with specific features to handle high temperature, gas, corrosion, etc. Problems discovered in field trials have allowed unique rubber formulations and construction innovations for which patents have been obtained. One result is a potentially "universal" cable able to handle high- and low-temperature ranges, be specially suitable to high gas-pressure applications, and have a general-purpose cable price. The CL-81 cable from the Centrilift Division of Borg-Warner Corporation, shown in Figure 2, has already shown a great deal of encouragement. Its material—a patented oil and water resistant, broad temperature range, tightly crosslinked EPDM—has gone through extensive laboratory and field testing. The CL-81 cable is expected to be available commercially in the near future.

There are also a number of highly exotic and expensive cable developments which have appeared and are in test here and there. Time will tell which will pass screening and field tests, meet the manufacturing and cost requirements, and appear as commercial products available for direct applications to the oil field. In the meantime, the cable selection process described here will be useful to both the developers and the users in standardizing the industry.

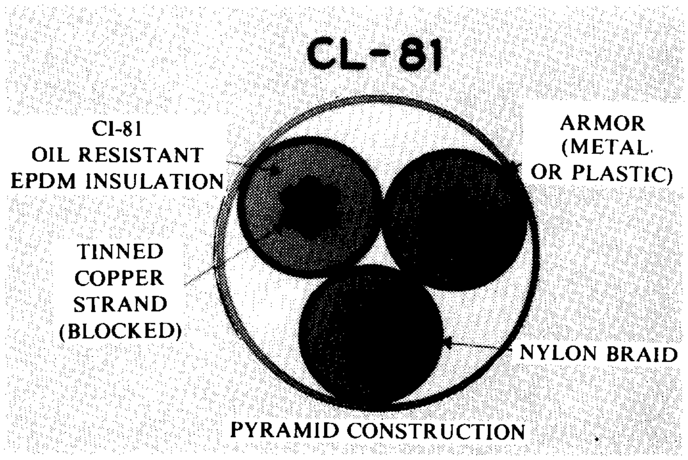

FIG. 2—CL-81 CABLE CONSTRUCTION