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ESP Cable Design and Application Fundamentals

From Cable Design to Operational Success

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Abstract:

This decade has seen tremendous progress in ESP cable development that has extended cable run life in even the harshest well conditions, However, as the range of cable offerings has increased to address specific operating conditions, greater demands are placed on selecting the right cable for any given application. This paper explains the crucial drivers involved in selecting ESP cables and summarizes, in straightforward terms, how cable design relates to service performance. Petroleum and Specifying Engineers who want to increase run life and obtain maximum value for their ESP Cable investment will find this paper both interesting and beneficial.

Background Discussion:

Today there is a wide range of ESP cable options because the ESP cable industry has been increasingly diligent in designing cables to optimize run life under different specific well conditions. In fact, there are literally hundreds of different ESP cable designs and variations to choose from. To give some insight as to how this vast array of options evolved, let's look at some basics. First of all there are both round and flat cables usually offered in at least four popular wire gauges. Plastic or rubber insulation is available which can be protected by tapes, braids, extruded barriers or lead (and various combinations thereof). All these conductor assemblies are encapsulated in a rubber jacket of which there are two basic polymers...nitrile or EPDM, and a wide variety of finished compounds made from these base materials. Lastly, the cables can be covered with one or more layers of galvanized steel, stainless steel or monel armor, each of which are available in several gauges (See Figure 1).

Needless to say, no one offers all these possible cable combinations as standard products. However, cable manufacturers who specialize in ESP cable do have several hundred popular part numbers of which about 250 different cables represent about 80% of the ESP cable business. It is readily apparent that informed choices must be made by cable Application Engineers and end users to select the most appropriate cable for specific well or field conditions.

Several industry standards have been written to assist in specifying, testing and installing ESP cables (see References 1, 2 and 3). However, even though these standards are of real value, they do not lay out the basic issues involved in cable design and selection.

Cable Selection Begins with Well Conditions

The process of selecting the correct ESP cable begins by understanding the well conditions and the proposed completion package. Answers to the following questions bare directly on the ESP cable selection process.

Does the completion geometry dictate using a flat cable or will a round cable fit? This can be determined by looking at the clearance between the ID of the casing and the OD of the production tubing along with the thickness of cable bands or clamps to be used and comparing them with cable dimensions. If a flat cable must be used, this will immediately scale down the breadth of acceptable cable options.

How deep will the pump be set in the well? Knowing this will help determine the voltage drop during start up, which will influence the conductor size needed.

How hot is the well? Bottom hole temperature is a major factor in determining how hot the conductor in the cable will become when the pump is operating. Conductor temperature is the single most important determinant of what type of insulation and cable design is suitable for a given well.

How much current will the motor draw? Electrical current and bottom hole temperature are the most important factors in predicting the cable's operating temperature. Other factors involved include cable geometry along with insulation and jacket thermal properties. Data tables have been generated to predict the conductor temperature under specific conditions. Consult these tables during the selection process. (See References 4,5 and 6.)

How gassy is the well? Insulation and jacket materials are made from synthetic rubber, which in turn are made from hydrocarbons, most notably oil. Like oil, synthetic polymers readily adsorb gasses when placed in a high-gas, high-pressure environment. Just as oil has a bubble point, so do rubber and plastic. In other words, if there is a lot of gas in the well, there will be a lot of gas adsorbed into the cable. The cable design must provide a means of keeping the cable from experiencing decompression expansion or even exploding when the pressure in the well drops each time the pump is energized. Gassy wells require special attention in terms of cable design which must be carefully considered during the cable selection process. This will be discussed in greater detail later in this paper.

Is there H_2S in the well? Knowing the concentrations of H_2S in the well is very important because H_2S chemically reacts with copper to form copper sulfide. This can lead to cable failure. The rate of attack depends primarily on the concentration of H_2S in the well and the temperature of the well. The most common method of preventing H_2S attack is using a lead-covered cable.

How corrosive is your well? Most ESP Cables are covered with a wrapping of metal armor to provide physical protection and decompression containment. Loss of the armor will lead to premature failure. Special alloy armors may be required or corrosion inhibitors might be needed to preserve the integrity of the armor. Special cables can also be made with corrosion inhibitor tubes inside to reduce the cost of chemical injection.

Do you need special instrumentation or hydraulic controls in the well? By anticipating these needs, control and signal lines can be built into the cable to improve reliability and reduce installation costs.

What reservoir changes do you foresee? Anticipating changes in the field such as introducing a CO, flood or foreseeing increased water cuts with corresponding motor size increases can be very important in selecting cable designs suitable for long term service in the field.

What about surface conditions and facilities? How cold the cable gets during surface handling can have a significant effect on cable material selection. Also, the maximum weights that can be handled by trucks or cranes, deck space etc. need to be considered.

The above discussion merely outlines some of the basic information involved in making appropriate cable design recommendations. To get the best cable for any specific application, the Engineer must have a good understanding of both the intended application and available cable design options.

Performance from a Cable Design Perspective

Having looked briefly at some of the well conditions which effect cable selection, let's now take a look at the issue from another perspective by exploring performance advantages and limitations of cable design options. It is important to understand that while we will attempt to discuss major design issues, a paper of this brevity does not allow a thorough exploration of this topic. Hence, only the highlights can be covered here.

Round vs. Flat Cable: If the well allows a choice of either round or flat cable, we need to look at the pros and cons of each. Generally speaking, round cable is superior to flat cable because it provides more protection to the insulated conductors due to the presence of more jacket compound and a complete fill under the armor. Assuming the armor remains intact, round cable provides superior containment to the cable core, enabling round cable to better withstand decompression and oil swell forces without damage. Because pressure is naturally contained in a round shape and the space between the insulation and the inside of the cable armor is filled with jacket material, the cable armor acts to restrain and prevent any insulation expansion due to oil swell or decompression expansion.

Flat cable armor is not suitable for containing oil swell or decompression forces because flat cable has interstices between the single conductors and flat armor doesn't have the correct geometry. Unlike round cable, if insulation or jacket expansion occurs in a flat cable it will deform the armor, bending it upward and allowing the conductors to slide over one another. Insulation and jacket expansion can cause insulation splitting which can lead to electrical failure.

Another advantage of round cable is that it is naturally impedance-balanced due to the equidistant spacing between the conductors. Flat cables, by virtue of their parallel conductor configuration, have an inherently induced imbalance. Flat cable induced voltage and current imbalance is usually not a practical consideration in lengths less than 10,000 ft. unless the well is very hot and is pushing the thermal limits of the motor.

In general, providing there is room in the well between the production tubing and the casing, round cables is preferred over flat cable.

Solid or Stranded Conductor: Conductors can be made either from single solid conductors or from conductors made from multiple smaller strands. Solid conductors offer many advantages over stranded conductors in oil well cable (see Reference 7). Solid conductors are: smaller, they do not adsorb gasses into their interstices between the strands, they are easier to clean and splice, they offer a smoother surface to the insulation reducing electrical stress, and they are less expensive. Because repeated flexibility is not a design requirement for ESP cables, there are little or no technical reasons to specify stranded conductors. **As** these facts have become more widely known and manufacturers have modified some of their production machinery, solid conductors have become the configuration of choice in modern ESP cable specifications.

Tinned or Bare Copper Conductors: Tinned copper or a tin/lead alloy coated copper is usually used when polypropylene insulation is specified, where it serves to keep the plastic insulation from direct contact with copper. In certain well environments direct contact between copper and polypropylene can cause “copper poisoning” of the insulation which reduces its electrical strength and degrades its physical properties. Even though polypropylene producers offer several chemical additive packages to help inhibit this type of degradation, the long-term reliability of these chemicals is still in question. Consequently, tin or lead alloy coatings are still used to separate the copper from polypropylene insulation.

Synthetic rubber insulation does not react with copper, so the vast majority of all rubber insulated ESP cables are made with bare copper conductors.

Insulation: There are two basic types of insulation used in ESP cable, polypropylene and EPDM synthetic rubber. If the temperature of the conductor during service in the oil well is expected to exceed 205” F in non-leaded cable or 225°F in leaded cable, EPDM insulation must be used. Otherwise, the lower temperature rated and somewhat more cost-effective polypropylene insulation is the material of choice. The “backbone” of synthetic rubber ESP cable insulation is EPDM or ethylene propylene diene monomer which is compounded with as many as twenty other ingredients to make the EPDM based insulation used today. These compounds are specially formulated for oil wells to have low oil swell, fairly low elongation and high modulus. By contrast, insulation designed for surface applications such as power cable is not suitable for oil well service because it swells too much when exposed to oil. Most high quality ESP cable EPDM-based insulation is rated for conductor temperatures up to 450°F.

Again, temperature is the main determinant of what type of insulation is used and to a lesser degree, cable construction plays a secondary role. For example, poly cable's temperature rating is increased from 205°F to 225°F when it is protected and covered with an extruded layer of lead. Conductor temperatures above 225°F always require rubber insulation.

For lower temperature applications, polypropylene insulation is preferred. It has excellent electrical properties and, when used in its operating temperature range, it is physically tougher than rubber as well as being a less costly material.

Insulation Protective Layers: EPDM insulated conductors need protection from the oil well environment. To provide this protection, different types of protective layers are applied over the insulation. These layers vary depending on the oil well conditions where the cable will be used. Because EPDM swells when exposed to oil, a number of different protection layers have been developed to prevent excessive oil exposure. Starting with the lowest level of protection, thin tapes made of PVF are wrapped over the EPDM insulated single conductors to help keep oil out. The limitation here is that the tapes have an overlap that lets some oil seep through. To try to make the PVF tapes more effective a 50% overlap can be used and to add some containment, braids are often put over the tapes. Braid materials can be as common as nylon and polyester, which have temperature limits in water of about 250°F to more exotic materials with ratings up to 300°F or even 400°F for the most expensive engineered filaments. One step better than tapes and/or braids is a continuous extrusion of a high temperature plastic layer over the insulation known in the industry as an extruded barrier layer. This method has no overlaps to let oil get through to the insulation and it also adds electrical strength to the insulation system. Furthermore, it increases the chemical resistance of the cable and it automatically regulates the rate of decompression of gasses from the primary insulation in the cable. Extruded barriers are made from fluoropolymers such as PVDF rated up to 320°F and FEP (Teflon) rated up to 400°F. **A** detailed performance comparison between barrier layers and tapes is presented in a paper titled "Comparing Extruded Layers and Tapes in ESP Cables" (See Reference **8).**

In summary, numerous options exist to protect EPDM insulation. Options range from the lower cost tapes and braids to higher performance, continuous extruded layers of advanced engineering thermoplastics.

Lead Layers: Some oil well cables have high levels of H_2S which can cause conductor damage due to chemical reactions with the copper. To prevent this, a layer of lead is extruded over the insulation. In the case of lead covered polypropylene insulation, lead provides protection from

H_2S and has the added advantage of increasing the rated conductor temperature to 225°F. When lead is used over EPDM insulation, fabric tape or a braid is placed over the lead as a manufacturing aid to minimize distortion of the lead during armoring. Tapes or braids are not required when the primary insulation is made of polypropylene because this harder, low temperature insulation is more difficult to distort during the armoring process.

Lead cables are usually made in parallel flat configurations although they can and have been made in round profiles for added containment and protection.

Jackets: Rubber jacket materials are used to protect the insulation from physical damage. Also, in round cables, jackets fill the space between the insulated conductors and the inside of the armor so that the armor can effectively contain the whole cable from oil and decompression swelling. Two different types of rubber are used for jackets, Nitrile rubber and EPDM rubber. Nitrile rubber is very resistant to oil swelling but has an operating temperature limit of 280°F. EPDM rubber swells more readily in oil but has a working temperature of up to 400°F.

Jacket materials, like all rubbers, are compounded by a Polymer Chemist for specific properties. In the case of oil well cable, the chemist works to make the material have a higher modulus. In other words, he tries to make it hard to stretch so it will add further containment to the underlying insulation. Some patented methods of increasing the modulus of rubber include adding fiberglass to the rubber matrix which greatly improves the jacket's containment abilities. The overall diameter of extruded cable jacket must be carefully controlled to ensure a good tight fit between the jacket and the outer metal armor so the armor will not be too loose and slip with respect to the core or be so tight that it damages the cable.

Armor: In flat cable, the outer armor's sole function is to provide mechanical protection to the underlying conductors. However, in round cable, the armor has two important functions: it provides mechanical protection and it provides containment to the cable core to prevent it from swelling due to oil exposure or decompression (see Round vs. Flat Cable discussion above). Armor is usually made of mild steel with all sides of the metal strip galvanized to slow down corrosion. Galvanized steel is offered in a number of thicknesses with the heaviest materials used predominately on round cable because it is easier to form thick metal strip over a round cable core than over the oblong profile of a flat cable.

If the well is very corrosive, other specialty armor metals can be offered including 316L stainless steel. Monel is almost always used on motor leads because it is easy to form around the thinner motor lead cable and the motor lead operates in the harshest part of the well.

In summary, many more ESP Cable design options exist than most users are aware of. So, when making cable selection decisions, it is very useful to consult with an experienced ESP Cable Applications Engineer. Only by understanding the well conditions, including anticipating changes in the field and by knowing how cable design options translate into cable performance, can the optimum cable be selected.

As with all components of the ESP pumping system, combining field experience and manufacturer's knowledge is the key to extending system run life.

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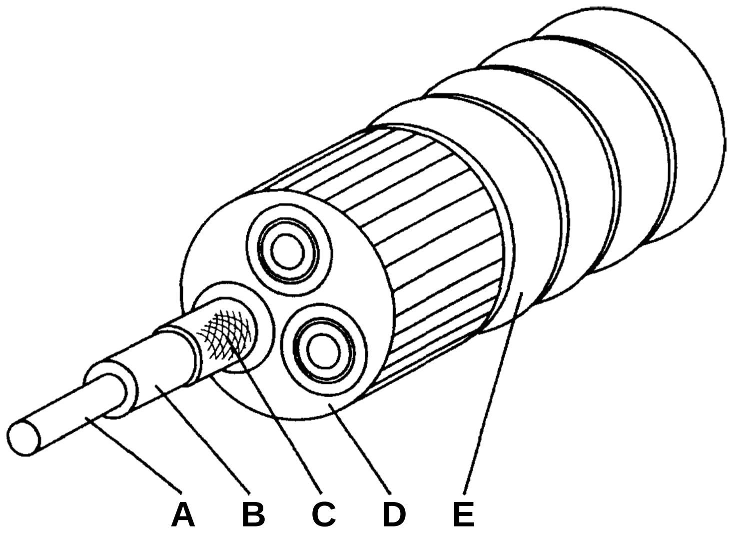

A	Conductor	Size? Solid or Stranded? Tinned or Bare?
B	Insulation	Plastic or Rubber? What Temperature Rating? Voltage Rating?
C	Insulation Coverings	Tape/Braid? Extruded Barrier or Lead?
D	Jacket	EPDM or Nitrile? Fiber Reinforced or Not? Temperature Rating?
E	Armor	Galvanized Steel, Stainless Steel or Monel? .015, .020, .025, .034 or Double Armor?

Figure 1 - Basic Options By ESP Cable Component