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Preventive Maintenance of Electric Submersible Pumps and its Relationship to Root Cause of Failure Analysis

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Abstract

We live in working environments where it is difficult if not career limiting, to say "no" to job assignments from bosses and colleagues. Pulling before catastrophic failure is normally not done, except in rare instances. Units are rarely pulled until total electrical failure occurs and the unit will not restart. Many times these restart attempts, after the systems have gone to ground, destroys the evidence needed to determine the reason for failure.

Proper diagnostics of a unit that shuts down on overload could, in many instances, reduce repair costs for the unit, provided they are pulled prior to restarting. However, this is not the general procedure in the field. Many lease operators do not have the equipment or training to troubleshoot ESP systems after they have gone down and, being pressured for production will automatically attempt a restart as soon as they discover the failure.

Producing wells can be monitored, and corrections in operation such as incoming power, wellhead pressure, casing pressure, etc., can reduce the stresses and increase the life of an ESP system. Also, use of proper monitoring techniques can aid in determining needs for replacing equipment and can reduce the repair costs if units are pulled and/or resized prior to catastrophic failure. The operator is the most important determining factor on run-life and is probably the least trained in the operating and design limitations of ESP systems. Further improvement in RCFA in the ESP field is undoubtedly in the hands of the ESP users. More manufacturer-user RCFA teams working together are becoming necessary to extend ESP run times.

The objective of this paper is to provide modifications to Root Cause Failures Analysis (RCFA) methods, specific to ESP applications and show how many of the methods can be applied as Preventive Maintenance in the ESP field. It will be supported by case study from the Meekwap field where the "Time between Failures" (TBF) was tripled as a result of close cooperation between field operator and ESP manufacturer.

Field Introduction

The Meekwap field is located in the Swan Hills area in North-Central Alberta, Canada. It is under an extensive waterflood with 800 – 1600 m^3/d of source water from the Debolt formation injected into the Nisku. Field flood pressure ranges from 22 MPa to 15 MPa. The reservoir is mix of dolomite and limestone and belongs to Nisku formation. Dolomite generally utilizes ESP's (11 wells) for production, whereas Limestone area is generally produced with conventional rod pumps, and a total of 20 producers are in five production sections. Emulsion is sour (up to 60,000 ppm) with high chlorides content (3,000 ppm). The oil gravity is 36 degrees API, water gradient is 10.9 kPa/m and Bottom Hole Temperature (BHT) is 86^{o}C.

Root Cause Failure Analysis - proper approach to failure analysis

RCFA is a disciplined problem solving methodology, used to determine root causes of specific failure events. The following process is necessary to implement a successful RCFA:

* **Determine the failure mode.** This is commonly mistaken for the root cause of failure. Mode of failure is how the failure surfaces, not why the failure happened. It is very common that people accept the statement "motor burnt" without asking what caused it.

* **Determine the failure cause.** Root Cause of Failure answers the question "Why?" and at the same time explains "how" it happened.

* **Estimate the extent of the damage and the likelihood of additional failures.** It is important to search for other potential ESP failures caused by the same Root Cause of Failure.

* **Design and implement the appropriate corrective action;** and follow-up to ensure that the corrective action is first implemented and verify its effectiveness in preventing another failure.

The most critical part of Root Cause Failure Analysis is to determine the Root Cause of Failure. All too often, maximizing run life is not accomplished because ESP failures are not properly identified. The first flaw discovered in the failure of an ESP system is often given full responsibility for the failure. This method of analysis can result in a much shorter average runlife in a given well and/or field. Maximizing run life of ESP's can only be accomplished through proper analysis of failure modes and investigating all aspects of the ESP system. It is important to note that when investigating a single failure, the entire field operation and procedures, along with the complete history of ESP performance in that field must also be taken into account. Therefore, in order to implement a successful RCFA, the following steps must be undertaken:

Shop personnel involved in manufacturing, field service, rig crew and operators must be aware about importance of RCFA

Review previous Root Cause of Failure (RCF) for the given well. In many cases, a failure trend specific to, for example, the well conditions or the field service technician involved in the equipment installation or to the operating procedure has been identified, etc.

Review previous pull history. It is often possible that some damage from previous installations was not caught during equipment testing and the current failure is actually the result of damage caused from the previous installation. A good example is motor failure due to insulation fatigue resulting from overheating due to a plugged pump.

Collect the production data for the first few weeks after installation, as well as for the last few weeks before the failure. It is extremely important that somebody closely monitor the ESP unit following start-up until the well has stabilized, and then the VFD settings need to be verified. It is also good practice to produce the well to the test separator as often as possible to get an accurate accounting of production. Calculated well production from field data is often misleading, especially in new and dynamic fields. Remember, there can never be <u>too much</u> good-quality production data. The production data from initial weeks is used to verify well information used for application design. Data from the weeks immediately preceding the failure can provide insight to potential changes in well performance or pump wear.

Apply collected production data to original design and verify ESP operating conditions. This type of well maintenance can verify the reservoir data used for the original application design. Monitoring the application in this manner can often allow early detection of pump problems, or pending failure, and thereby prevent costly motor failures. Data collected should include operating parameters such as tubing and casing pressure, pumped fluid volume and composition, amps, drive output volts, operating speed, fluid level or BHP, BHT.

Compare drives start-up documentation attached to installation report with drive settings before failure. In many cases, especially with gassy wells, it has been observed that underload settings on the drive were changed and prevented shut down of the drive when the pump gas locked. Another example of the need for review of documentation resides with the common practice to use an oversized motor in low flow and hot wells to prevent motor overheating. Unfortunately, in these cases it is possible that the motor operating current can be very close to idling current, and thus the UL settings will not protect the equipment in case of pump plugging. In these cases, it is recommended use a flow switch at the wellhead to improve equipment protection.

Examine drive repair history. Faulty drives or low quality incoming power can be the instigators of electrical failures; often the drive at the end of power grid is exposed to the worst operating conditions. Most often, following examination, incoming power problems become very obvious and isolation of these problems can greatly assist in maximizing ESP run-life.

Perform drive amp-chart analysis, or analysis of data available from data collectors or directly from the drive itself, in the case of some new generation VFD's. It is important that operators include all required data on the amp-charts, otherwise the use of the amp-charts becomes very limited. Information that should, ideally, be recorded on amp-charts include: mode of VSC operation, operating speed, recorded amps from all three phases, down-hole pressure, drive output voltage, transformer ratio, casing and tubing pressure. Many amp-charts are often missing the most important information – location, when it was put on, and when it was taken off!

Download of drive history from drive memory prior to attempting the ESP's restart. Often when a unit fails, the first impulse is to attempt a restart, and more often than not, multiple restarts are attempted. If these attempts occur before drive history was download, important information can be lost, especially if the shutdown is actually the reason for pull. Downloading drive history should be a part of operating procedures.

Evaluate the information available from the pull report (all fluid should be drained on the rig floor in vertical position if the motor-seal assembly cannot be sent to shop for air testing).

Verify compatibility between the well treatment chemicals used and the materials used within the ESP, if this was not done before well treatment.

Verify compatibility between down-hole conditions and materials used within ESP. Examples of incompatibility include Aflas with condensates; Viton with amine-based well treatments; most stainless steels in a sour environment, etc.

Test, disassembly and inspect failed equipment as required. Dismantle inspection is a critical part of the evidence gathering process necessary to support a successful failure analysis. All evidence should be documented, regardless of its relative importance to the inspector at the time. No interpretation of the evidence should be made during the dismantle inspection so as not to bias the evidence gathering process toward a specific cause of failure. **Therefore, it is** best to not begin conducting a failure analysis until after the evidence gathering process is complete.

Delivering Root Cause of Failure by RCFA team.

Looking for failure trends within manufacturing, well conditions, or operating methods.

Root Cause Failure Analysis and it's Relationship to ESP's Preventive Maintenance

ESP Preventive Maintenance should include:

Collection of production data and operating parameters such as tubing and casing pressure, pumped fluid volume and composition, amps, drive output volts, operating speed, fluid level, BHT as often as possible (at least biweekly)

Application of collected production data and operating conditions to original design to verify ESP operating conditions

Verification of compatibility between chemicals proposed for well treatments and materials used within ESP. Published data should be sufficient in most cases but it is recommended to make use of test coupons for evaluation, as there are many grades of a particular elastomer, for example, and they can react differently.

Verification of compatibility between down-hole conditions and materials used within ESP prior installation. It is not unusual for the reservoir conditions to change during the life of the field. When starting enhanced recovery techniques, the ESP system must be monitored frequently because of the potential for causing the unit to operate outside the design parameters. Consultation between Customer/User and ESP manufacturer when well optimization is the desired goal.

Thus, many of the methods used during RCFA can be applied as Preventive Maintenance in the ESP field.

Coatings

All pumps built for this field are designed as floaters or ARM. On a number of occasions heavy scale locked the impeller on the pump shaft resulting in thrust bearing overload. The metastable iron sulfide (FeS) product of H_2S corrosion and water borne $CaSO_4$ are dominant scales found within equipment from the Meekwap field. The traces of nickel sulfide (Ni_3S_2 and NiS) and iron-nickel sulfide ((Fe,Ni)9S8) occurred as well.

Coated stages, intakes and discharge have been a huge contributor to the success of combating scale. Impellers and diffusers are made by sand casting and internal components cannot be machined and have rough surfaces, which allow scale to build up.

Internal pump coating is a relatively new method to prevent scale depositions by reducing porosity of the down hole pump components, preventing turbulent flow, reducing streaming potential, and eliminating absorption sites. Two families of resins, Polytetrafluoroethylene (PTFE) and Hexafluoropropylene (FEB), are presently used in the ESP industry. They are applied as a thin film of fluoropolymer coating in applications where high release (non-stick) properties are required. FTFE resins especially have exceptional resistance to deposition of scale on downhole equipment.

Equipment Upgrades For Tight Hole Configuration

During a first two weeks of May 1998, we had conducted a number of tests with equipment designed for 4-1/2” casing. The necessity of these tests was driven by the difficulty experienced in some fields during installations and pullouts of the Centrilift Slim Line equipment in tight hole applications. The most common reason for cable failure was mechanical damage during installation. The only solution to tight hole application was to development of specialized equipment for this application. To address equipment problems for installation in 4.5” heavy casing we have developed and are presently using:

a) Discharge was modified to allow more space for cable to go past pump.
b) The seal section’s housing diameter was reduced to allow more clearance for Motor Lead Extension (MLE).
c) New, flexible base was design for the seal assembly with deeper cable groove, allowing a smoother cable transition between seal and motor
d) New pothead and motor head were design with 3.75” overall diameter (after assembly), which eliminated rub buttons and minimize overall equipment diameter
e) Bolt on centralizers and cable protectors

Equipment Upgrades For Sour Environment In Meekwap

Some of the failures related to operating environment were caused by high concentration of chlorides and H_2S. We will present in this paper presents equipment modification requirements for resistance to harsh environments in Meekwap field for petroleum production with the Electric Submersible Pumping System (ESP). These are targeted to be used in hydrogen sulfide (H_2S)-bearing hydrocarbon service and when the fluids being handled are three-phase crude, water, and gas

Over the past five years the Canadian division of an ESP manufacturer has concentrated its energy and resources towards the development of ESP equipment for use in harsh environments, especially with high hydrogen sulfide concentration. This ESP manufacturer has been successful in H_2S environments such as South Sturgeon, Clive and Wimborne fields. As a result of the ESP manufacturer’s experience in sour environments and equipment failure investigations, the metallurgy of some components as well as the design of ESP components were modified. Pumps, Rotary

Gas Separators (RGS), seals and electrical connectors (2pce MLE) were modified to “High H_2S Environment Equipment Upgrades” standards.

Equipment built to "ESP for High H_2S Environments" has been upgraded as follows:

PUMP: shaft metallurgy is upgraded to the Nickel-Copper Alloy for the shafting for all horsepower requirements. No Stainless Steel, Brass or Bronze parts are allowed within the pump unless they are plated with corrosion resistant alloy. Carbon Steel, nickel reach austenitic cast iron and Nickel Alloys are the only materials used within the pump. Housing is externally coated with Nickel-Copper Alloy using a spray technology eliminating porosity of the coating. All standard snap-rings used within standard assembly are replaced with snap-ring made of Precipitation-Hardenable Nickel Alloy. Only TFE Propylene o-rings are used.

INTAKE: shaft metallurgy is upgraded to the Nickel-Copper Alloy for all horsepower requirements. No Stainless Steel, Brass or Bronze parts are allowed within the intake unless they are plated with corrosion resistant alloy. Carbon Steel and Nickel Alloys are the only materials used within the intake. Housing is externally coated with a Nickel-Copper Alloy using spray technology eliminating porosity of the coating. All snap-ring used within standard assembly are replaced with snap-ring made of Precipitation-Hardenable Nickel Alloy. Only TFE Propylene o-rings are used.

RGS: shaft metallurgy is upgraded to the Nickel-Copper Alloy for all horsepower requirements. No Stainless Steel, Brass or Bronze parts are allowed within the intake unless they are plated with corrosion resistant alloy. Carbon Steel, WC and Nickel Alloys are the only materials used within the intake. Housing is externally coated with Nickel-Copper Alloy using spray technology eliminating porosity of the coating. All snap-ring used within standard assembly are replaced with snap-ring made of Precipitation-Hardenable Nickel Alloy. Only TFE Propylene o-rings are used.

SEAL: Standard configuration is a double-bag (one bag per section) tandem seal. High-density TFE Propylene elastomer for bags and Nickel-Copper Alloy bag clamps are used. Nickel-Copper super-alloy shafts are used in both sections. Corrosion resistant bushings are used in the upper guide and head of upper tandem section. Two premium face mechanical seals with Nickel-Copper Alloy hardware are used in upper tandem. Carbon Steel and Nickel Alloys are the only materials used within upper tandem with the exception of thrust bearings and check valves. A special grade of Stainless Steel is used for the check valve body. Housing is externally coated with Nickel Alloy using spray technology eliminating porosity of the coating. Only TFE Propylene o-rings are used. All snap-ring used within standard assembly are replaced with snap-ring made from Precipitation-Hardenable Alloy. Thrust load is transfer to Lower Tandem which utilize Corrosion Resistant thrust bearing.

MOTOR: Housing is externally coated with a Nickel-Copper Alloy using spray technology eliminating porosity of the coating. Nickel-Copper alloy fill valve and vent plugs are used. High-density TFE Propylene elastomer O-rings and a special grade of motor oil are used as well. No Stainless Steel, Brass, Bronze or Copper parts are allowed within the I-block unless they are plated with a corrosion resistant alloy. Nickel alloy thrust runner key and split ring and High Load thrust runner are the only allowed components. All copper wires within stator are Epoxy capsulated.

MLE: “Two Piece Lead-on-Lead” pothead has nickel rich austenitic cast iron body, double metal-elastomer sealing and Lead sheath cable with Monel armor.

CABLE: Lead sheath cables with carbon steel armor. No flat guards are used. Monel bands and clips are standard.

Culture Change

Management endorsed field specific “Hostile Environment Specifications.”

A failure review was done for all sizes of ESP’s and great effort was placed towards resolving top failure mechanism

Equipment upgraded each turnaround.

Cost per turnaround has increased because of equipment improvements and equipment has operated longer due to approx. 300 % increase in run time.

ESP well servicing cost has increased by approximately 50%. But overall expenditures have declined dramatically.

Wells are treated on an individual basis. Equipment tear down is Tusk witnessed and both parties work at problem solving and correcting problems.

Wells are optimized on a quarterly basis: all details are considered.

Gas separators have been removed if not needed. In the past, Gas separators were used ‘just in case’.

ESP’s have been raised up the hole, if allowed, which decreases head required, power requirements, cable length (area of particular vulnerability).

Centrilift representatives provide onsite training to operators on a regular basis.

Future: will remain proactive. Are planning an independent power survey.

Looking at 375 candidates for other application.

Tusk purchases stock on specialized equipment prior to failure to reduce downtime on wells (eg. 375 series pothead and motor head).

Have implemented cable service factors:

6 – 7 for 375 series

8 for 400 & 513 series equipment

Frown on splicing new cable onto old. Prefer changing out entire cable.

Results/Conclusions

Previously, ESP run times were averaging 200 days, resulting in approximately 12 days of lost production per year per well for a total of 3000 bbl oil.

Now ESP run times are exceeding 600 days (see graph 1), causing a decrease in lost production of 2000 bbl/day

Measurement has been relatively and tracking has been relatively easy because of small field and consistent supervision and operator care.

In 1997 we aimed for a one-year ESP run life average. In 1998 we aimed for a two-year run life average.

Tusk is a strong believer in working with the supplier, pooling resources for the best possible end product. We feel that constantly blaming suppliers for any problems and entering into conflicts regarding warranty issues adversely affects the bottom line.

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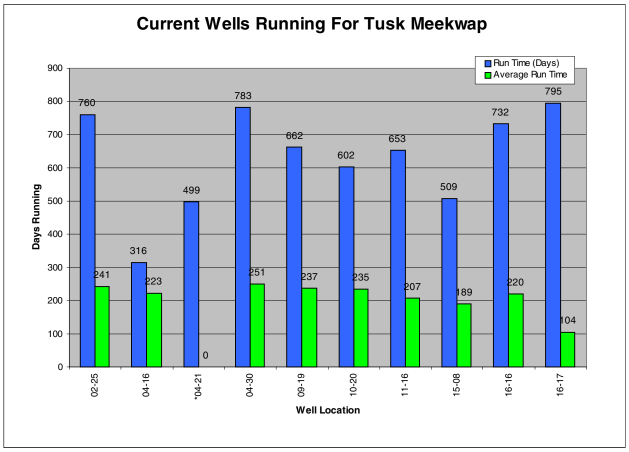

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