WATER DETECTION SYSTEMS FOR USE WITH ESP MOTORS

Rod Storey
Chevron U.S.A. Production Company

Introduction

Many ESP failure modes result in the ingress of water into the motor resulting ultimately in motor electrical failure. Knowing that the isolation of the motor from well fluid has been compromised, would allow the option of pulling the unit before electrical failure, significantly reducing the cost of repair. Various methods have been used to monitor insulation resistance to determine the electrical condition of the motor and cable, however, these methods are relatively expensive, and do not provide an indication until the insulation system has already been affected. This paper describes a method of detecting the presence of free water at the bottom of submersible motors. Fifteen such units are installed and functioning as expected, however, the benefit is yet to be demonstrated.

Theory of Operation

The water detection system uses the common technique of impressing a constant DC current onto the power system at the surface through an LC filter. A conductance probe is located at the bottom of the motor, connected to the neutral point of the wye connection. The probe is mounted internally to the motor base, housed in a perforated plastic shroud, and is completely surrounded by insulating oil. As water enters the motor and displaces the oil around the probe, DC current will be conducted to ground. The DC voltage required to support the constant current is monitored at the surface. This voltage is limited by the DC supply voltage, and will be at its maximum until the resistance to ground through the water is low enough to establish the preset constant current. Beyond this point the DC voltage measured at the surface is proportional to the resistance to ground. The DC voltage is then fed into an analog input on a motor controller or variable speed controller. The DC voltage is monitored by the host motor controller, and an electrical contact is actuated, if the resistance drops below a preset value. This contact closure can be used to indicate the problem or turn the pump off.

Conclusion

Though the benefit of such a system has not been demonstrated, there is optimism that this type of device offers a low cost means for determining that water has entered the motor.

Overview

Background: Attempts to extend the run lives of submersible motors has led the industry to examine the concept of detecting the entry of foreign materials into the motor housing. Materials outside the motor in the well environment have very low dielectric constants and represent a considerable threat to the operation of standard submersible motors. When well fluids are introduced in the motor, in quantities sufficient to reduce the insulation strength of the oil below the motor operating voltage. a motor failure due to Phase-to-Phase or Phase-to-Ground fault is unavoidable. Production demands to monitor the motor environment for the entrance of well fluids, water being the principle component. has led to the misnomer of water sensor.

Concept: The design focus of the water sensor project was the early detection of well fluid based contamination of the motor insulating oil during normal operation. The impetus of the detection is placed on on-line reporting of the condition of the insulating oil to a surface control unit. The surface controls would then utilize the information to determine if motor operation should continue under current conditions. To minimize the time between the entrance of the well fluid and detection. the sensor is located at the top of the motor assembly. This allows the sensor to detect fluids, entering from the equalizer (protector), that are mixed with the insulating oil by rotation of the thrust bearing disk. The output of the sensor is a 80 Kilohertz to 200 Kilohertz signal that represents the current dielectric strength of the insulating oil. The signal from the sensor is capacitively coupled to the motor power cable and de-coupled from the power cable at the surface. The signal is then directed through a bandpass filter, to filter noise, and converted to 0-10 VDC signal proportional to frequency. the 0-10 VDC signal can be connected to any compatible measuring system, or attached to a local display.

Surface Equipment

Surface Instrumentation: The surface instrumentation is comprised of a de-coupling capacitor, filter/converter board, and display unit. The de-coupling capacitor is identical in design to the coupling capacitor utilized in the sensor package. The filter/converter board acts to filter out unwanted noise. and converts the signal from the sensor to a 0-10 VDC signal proportional to frequency. The signal from the water sensor is converted to a 0-10 VDC signal by a frequency to voltage converter. The 0-10 VDC signal is sent to the display unit which displays the sensor signal in KV. The display also incorporates the operation of two relays to interrupt motor operation should the KV reading fall below a preset value. The display allows the user to set two operating switch points. The first point can be configured as a warning in the drop of dielectric strength. The second point can be configured as the termination point for normal operation. Another option for connecting the water sensor surface instrument to downhole pumping systems, is to connect the 0-10 VDC signal through a signal conditioner (if required) to the motor protector.

Downhole Equipment

Sensor Principles: The sensor unit detects dielectric strength of the oil by measuring the charge buildup on a capacitor, which utilizes the motor insulating oil as its insulator. Changes in the insulating oil result in changes to the charge buildup on the capacitor. The sensing capacitor is connected to a Voltage Controlled Oscillator (VCO) which translates the changes in charge buildup to a variable frequency. The center frequency of oscillator operation is calibrated to 200 Kilohertz by the value of resistor R3. The change in frequency from the VCO is proportional to the change in dielectric strength of the motor insulating oil (measured in KV). A reading of 32 KV is proportional to 200 Kilohertz. While a reading of 16 KV is proportional to 100 Kilohertz. The VCO output signal is conditioned by a class “B” push-pull amplifier and capacitively coupled to the motor power system on one phase of the high voltage power line.

High Voltage Coupling: The sensor output is capacitively coupled to one phase of the high voltage motor supply system. The selection of the coupling capacitor is based upon the need to minimize the attenuation of the 80 KHz to 200 KHz signal, while effectively blocking the 60 Hertz fundamental and its harmonics. The lowest passable frequency for the coupling design was assumed to be 10 KHz. The sizing of the capacitor was based upon:

$T = R$ where: $T = 1/f$ (lowest frequency)
R = Motor System Resistance
C = Capacitance (uF)

Sensor Power Supply: The power supply to operate the sensor electronics is derived from a toriodal transformer placed on one of the motor leads. The inductively coupled signal is converted to a positive 15 volt signal by a full wave bridge and filter capacitors. The voltage is regulated to 15 volts by a zener diode. Maximum ampacity of the power supply is limited to 19 mA DC. The sensor requires a maximum of 8 mA during normal operation.

BLENDER INTAKE SYSTEM FOR HIGH GLR PUMP APPLICATIONS

In the early 1980’s, Chevron was operating the Rangely Weber Sand Unit with 330 ESP units, 75 rod wells and 160 injectors. The field was averaging 38,000 bbl/day oil and 500,000 bbl/day water with very little gas production.

In 1986, Chevron introduced a CO_2 flood EOR project to the field. This project brought high gas/liquid ratios to our producing wells. This change drastically affected our ESP system operation. To handle these high GLR’s, Chevron started installing rotary gas separators. Reliability seemed to be a major problem right from the start. Out of the first 20 separators installed, five had bearing problems resulting in twisted shafts in the first 90 days of operation. Four others parted due to the auger cutting the housing and resulted in fishing jobs. Two others cut into the flat cable and shorted out, causing them to be pulled. At least these were not fishing jobs.

As you can see from our history, we had several problems with our rotary gas separators. We tried several gas handling solutionS, (i.e., shrouds, reverse shrouds, flush systems, reverse slow intakes, and welding closed the discharge holes in a rotary gas separator). This led us to the blender design being discussed and shown here.

Field Trial Number One

We installed a 2800 bbl/day rebuilt pump with a blender in one of our gassy wells. This well had a history of tearing up any pumps installed in it due to the changing rates through the pump. This 2800 bbl/day pump with a blender produced the low rate of 800 bb/day with 3MM cu. ft. CO_2 gas to the high rate of 3400 bbl/day with 2MM cu. ft. CO_2 gas. These production rates changed with our WAG cycles every 30 days. This well was pulled after eight months to look at the equipment. This was two months longer than any previous equipment had lasted in this well. The pump was sent in for inspection/teardown. The top two stages, middle two stages, and bottom two stages were sent to Chevron for inspection. All other stages were used in the rebuilding of the pump. All stages received at Chevron were inspected and found to be good enough to rerun. This was a positive step in our search for something that worked in our field.

Field Trial Number Two

We call this the tear-up trial. We found a well-used motor (900 days run time) and a well-used pump (worn out, for repair, and shaft able to touch the sides of the housing). We installed this into a producing well to see what would happen to the blender. After 33 days, the unit locked up. We pulled it and found the top bearing torn up in the blender. The bottom bearing was still intact and the seal in the protector was still in good shape and able to prevent water entry into the motor. This showed us that the blender bearing support system was of a good design and able to handle radial wear of the ESP pump.

Problems Encountered

We had one fishing job due to the breaking of a blender housing. We had it x-rayed and found it to be a stress fracture. The pumps were tested and found to be bad. They were vibrating badly enough to break, or stress, the best of material. That was the only major problem we have encountered with these blenders. They do plug off with asphaltenes, scale, and frac sand as well as any rotary gas separator. The repair time seems to be taking longer than necessary. This is a minor problem and one to be resolved shortly.

Chevron has had as many as 67 blenders running at one time, and as few as 15. This is due to the repair turn-around time, and our continuous changing of our well production methods.

The blender costs vs. gas separator costs:

	Blender	Rotary Gas Separator
Cost	\$1700-1900	\$2800-5000
Repair	\$ 500 - 700	\$2500-3800

This is enough to justify a little longer wait for the repair of the equipment.

Blender Testing

We sent blenders to Centrilift's Claremore facility to test against their rotary gas separator. This let us understand more fully just how the blender operates and what the pump/blender relationship is in our wells. The testing setup was built by Centrilift at Chevron's request to do this comparative testing. We plotted the test results of the rotary gas separator and the blender. Of note was the fact that the separation tank was ineffective. The fluid mixture coming out of the pump was very well mixed with the air. This showed us that we had a very homogeneous fluid mixture.

The following facts were noted:

Fact One: ESP pumps start gas locking at 10-13% free gas at pump intake.
Fact Two: Rotary gas separators can handle 40% free gas and still let the ESP pump operate correctly.
Fact Three: The blender intake can handle 20-30% free gas.
Fact Four: Lowering the blender 15 feet allowed it to handle 10% more free gas.

Conclusion

The blender intake can, and does, help reduce gas locking in ESP systems. With higher submergence and higher bottom hole pressures, more free gas can be safely moved through the ESP pump without damaging the unit. This design works well in the Rangely field, and we plan at this time to continue the usage of blender units.

Comparison of the Performance of the Gas Separator and the Blender Design of Chevron

Objective:

To evaluate the performance of the Centrilift gas separator and the blender with GC1600, GC2200, and GC2900 pumps at several GLR's.

Test Setup and Procedure

The Centrilift Claremore test well facility was used for the test. The test arrangement is shown in Figure 1. A 7.00" diameter casing was used as motor jacket for 562 series, 50 HP motor. The motor jacket was sealed at the top end to prevent any air leakage. Using a U shaped 0.5" diameter copper tube, a measured amount of air was injected at the bottom of the motor. A packer was used to collect separated air from the gas separator for measurement. The pump discharge was collected in a tank where remaining air and water were separated and measured.

The 513 series Centrilift gas separator was tested with GC1600, GC2200, and GC2900 pumps at 0 and 40% GLR. Data were collected for five points between minimum and maximum operating flow limits using water and air mixture.

The 513 series Chevron Blender was tested with GC1600, GC2200, and GC2900 pumps at various GLR using a water and air mixture.

Test Results and Analysis

Raw data and corrected data were collected. Data were corrected for rpm. The blender was tested with the same three pumps and the same submergence as in the case of the gas separator. Another test of the blender was carried out with the GC2900 pump at a higher submergence to consider the effect of submergence.

As most of the gas was separated by the gas separator, the pump performance was almost the same for 0 to 40% GLR. It can also be seen that the pumps handled the remaining gas very well and did not choke. Head and BHP were slightly affected by the presence of air, but the differences were negligible. Efficiency remained almost the same. Gas separator was effective in separating 90+% of air.

The blender choked in the range of 20% to 30% GLR. The blender caused a very homogeneous mixture of air and water. The separation tank was ineffective in separating this mixture in a short time. Horsepower and efficiency data of the pump are not plotted as horsepower data for the pump includes the BHP for the blender. Also comparing head, BHP and efficiency data for the water only test for the respective pump with gas separator and with the blender show almost the same values. This indicates that BHP required by the blender is very small value and lift generated by the blender is also negligible.

The submergence was increased by lowering the test equipment in the test well by 15'. The original submergence was about 10'. Higher submergence helped to improve the pump performance. Therefore, it can be concluded that the blender may be able to handle higher GLR capacity at higher submergence and at higher downhole pressure.

Acknowledgments

We thank Chevron, Centrilift, and Oil Dynamics, Inc. for their permission to present this paper. I would like to thank Dick Knox, Centrilift; Kevin Metcalf, Oil Dynamics, Inc., and Ketan Sheth, Centrilift, for all the work done by them in the figures, graphs and text.

Rodney A. Storey is an Artificial Lift Technologist for Chevron U.S.A. Production Company in Rangely, Colorado. He has more than 22 years in the ESP industry. He has worked as Field Service Technician for REDA Pump Company and Oil Dynamics. He worked as an application engineer for Oil Dynamics also. He has worked for Chevron as an Electrician, ESP Technologist, and Artificial Lift Technologist.