High Temperature ESP Monitoring

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Final Report

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Patent Disclosure: The primary sensing method was under investigation within Schlumberger prior to the award being granted. This methodology has been submitted by Schlumberger for patent protection.

Notice: The field results displayed in the report are from client wells. Due to the sensitivity of this information and confidentiality obligations to the clients, the client names and well specific information is not included and any distribution should be limited.

Executive Summary

The objective of the High Temperature ESP Monitoring project was to develop a downhole monitoring system to be used in wells with bottom hole well temperatures up to 300°C for measuring motor temperature, formation pressure, and formation temperature. These measurements are used to monitor the health of the ESP motor, to track the downhole operating conditions, and to optimize pump operation.

Following the project award, Schlumberger expanded the technology search beyond the commercial gauge cooled by a Free Piston Stirling Cooler initially proposed to address the Enhanced Geothermal application. It was determined that a substantial development beyond the available funding and resources would be required to modify the commercial gauge design for it to survive unpowered at 300 °C for even a short amount of time. Therefore, a decision was made in March 2009 to stop the Free Piston Stirling Cooler development and concentrate on other methods currently under development for the Steam Assisted Gravity Drain (SAGD) market due to their higher likelihood of success.

The final approach taken was using a Downhole Sensor with Surface Electronics. Also, the initial product offering used a sensor already characterized for operation at 220 °C. This allowed the complete system to be developed, qualified, and field tested in parallel of characterizing and qualifying a new sensor for operation up to 300 °C. Due to commercial reasons, a 250 °C was developed as an intermediate solution. The sensor used in the 250 °C product is the same sensor to be used at the 300 °C solution.

The first Downhole Sensor with Surface Electronics system (220 °C) was installed September 18, 2009 in a SAGD well and operated until April 4 2010. It had a downhole temperature of 216 °C. At that time, the ESP motor failed and the system was pulled although the High Temperature ESP Monitoring system was still operating within expectations.

A 220 °C based High Temperature ESP Monitoring system was commercially released for sale with Schlumberger ESP motors April of 2011 following a successful field test campaign. The 250 °C system with the new sensor is currently in field tests and will be commercially released at the end of Q2 2011.

Two final items still need to be performed in order to deploy a 300 °C. These are to characterize the new sensor (drift, accuracy, repeatability, etc) for operation at 300 °C and to perform the required environmental qualification testing of this system at 300 °C. All the materials for the 250 °C system were selected for operation at 300 °C; however, these have not been verified through testing.

Accomplishments versus Objectives

The following table lists the High Temperature ESP Monitoring deliverables as stated in the Project Management Plan submitted 12 November 2008 along with the corresponding results.

Deliverables	Results
Feasibility results to verify the selection of the best technology to meet the overall system objectives of the project, particularly, reliable operation at 300°C for 3 years.	Several methodologies were investigated during the project and the final method selected was a Downhole Sensor with Surface Electronics configuration. The sensor targeted for the 300 °C application, which is the critical element, has been characterized and qualified for operation up to 250 °C.
A qualified 300 °C downhole ESP gauge system to measure motor oil temperature, formation pressure, and formation temperature.	A 220 °C based High Temperature ESP Monitoring system was commercially released for sale with Schlumberger ESP motors April of 2011 and a 250 °C system with the new sensor is currently in field tests and will be commercially released at the end of Q2 2011. The measurement system is now fully qualified, except for the sensor at 300 °C.
All required surface equipment qualified for transportation and deployment.	The award covered the cost of completing the development of a surface card that is installed in Schlumberger's standard wellsite acquisition and ESP motor control system. The surface card was fully qualified and was successfully verified to meet the operating conditions during field testing.
A thermal model of the motor to determine the maximum motor temperature from the motor oil, well temperatures, and estimated flow.	This development was done by Schlumberger and was not funded by the award. Motor oil temperature is one of the input parameters to the model in order to estimate the maximum temperature within the ESP motor. The maximum motor temperature is usually the limiting factor when operating in high temperature applications.

Introduction

The objective of the High Temperature ESP Monitoring project was to develop a downhole monitoring system to be used in wells with bottom hole well temperatures up to 300°C for measuring motor temperature, formation pressure, and formation temperature. These measurements are used to monitor the health of the ESP motor, to track the downhole operating conditions, and to optimize the pump operation.

Following the project award, Schlumberger expanded the technology search beyond the commercial gauge cooled by a Free Piston Stirling Cooler initially proposed to address the Enhanced Geothermal application due to technical issues. Schlumberger's current commercial gauge for ESP monitoring is only specified for three years of operation life at 150°C and qualified following an established qualification plan for a product with this mission profile. However, after additional investigation, it was determined that a substantial development beyond the available funding and resources would be required to modify the commercial gauge design for it to survive unpowered at 300 °C for even a short amount of time. Therefore, a decision was made in March 2009 to stop the Free Piston Stirling Cooler development and concentrate on two other developments due to their higher likelihood of success. These two new developments were chosen since they do not include downhole electronics.

- Downhole Sensor with Surface Electronics
- Fiber Optic Pressure System

Schlumberger was already developing these systems for the Steam Assisted Gravity Drain (SAGD) application with a downhole operating temperature of 250 °C. The development strategy for the EGS application was to determine the components that need to be changed in order to meet the 300°C requirement and add these to the scope of the development.

The first Downhole Sensor with Surface Electronics system was installed September 18, 2009 in a SAGD well and operated until April 4 2010. At that time, the ESP motor failed and the system was pulled although the monitoring system was still operating within expectations. Below is a portion of the data from the system. The maximum operating temperature seen was 216 C.

Following this successful field test of the system based on a downhole sensor rated for 220 °C, in mid 2010 the decision was made to focus on this solution only.

System Description

This Downhole Sensor with Surface Electronics based system uses a downhole pressure/temperature sensor for formation pressure and temperature and a Resistance Temperature Detector (RTD) made of Platinum for motor temperature. The motor winding temperature RTD is tied to the end turns of the motor.

Figure 1, RTD attached to ESP Motor Winding End-Turns

The sensor is integrated in the metalwork at the bottom of the ESP motor and ported to the outside for measuring pressure. Below is an assembly drawing of the monitoring system connected to the bottom of an ESP motor and a picture showing the sensor and connector internal to the motor.

Figure 2, Assembly Drawing

Figure 3, Picture of system without the housing installed.

The wires for both the RTD and sensor are integrated into a 7-wire cable and connected to the surface equipment for data processing as shown below.

Figure 4, System Diagram (Left), External Connection at base of motor on wellsite (Right)

Because of the high downhole temperature, the electronics are located at the surface and the signal wires are routed to the surface unit for excitation of the sensor and making the measurements. The monitoring cable transfers the power from the surface card to the downhole sensors and provides sense lines from the pressure gauge and the RTD for taking the measurements at the surface. The monitoring cable is normally terminated in a junction box at surface, after transitioning through the tubing hanger, where a flexible cable is then run through the cable trays to the surface card.

Figure 5, High Level System Diagram of High Temperature ESP Monitor System

The surface card provides excitation currents to the gauges. The current polarity alternates in order to cancel the Seebeck effect associated with junctions of dissimilar metals. As the temperature increases, this phenomenon becomes a noticeable source of error.

The block diagram on how the downhole sensors are routed to the surface card is shown in the following figure.

Figure6, Wire Diagram for 7 wire operation

Below is a screen shot of the acquisition and control software module developed for the High Temperature ESP Monitoring system. It integrates in a common software application that is currently used for interfacing/controlling Schlumberger surface equipment.

Figure7, Control and Acquisition Interface

System Specification

Shown below are the system specifications for the High Temperature ESP monitoring system.

Measurements

Parameter	Range	Accuracy	Resolution	Comment
Wellbore Pressure	0-3000 psi	± 10 psi	0.1 psi	
Wellbore Temperature	0 –220/250 °C	± 3 °C	1 °C	
Motor Winding Temp	0 –650 °C	± 3 °C	1 °C	RTD range up to 650 °C

Operational

Description	Specification	Comment
Sampling Rate	Once per minute	
Pressure Drift	15 psi / year	
Survival	1 year, 90% reliability	

Environmental

Description	Specification	Comment
External Pressure	5000 psi absolute	Also at ESP interface
Operating Temperature	220/250 °C for pressure sensor	Formation temperature
Survival Temperature	OT + 20 °C for 1 hour for pressure sensor	Pressure sensor may drift beyond spec

Characterization of New Pressure Sensor

The initial system incorporated a pressure sensor qualified for 220°C operation only. This system is manufactured by Schlumberger. The limiting factor of the sensor at this temperature is its long term drift performance. The application requires a pressure drift of no more than 15 PSI/year.

In order to operate at higher temperatures, a new pressure sensor based on a different technology was characterized and qualified for operation at 250°C. The new sensor is being developed with Paine Electronics.

Although the High Temperature ESP Monitoring system components (metalwork, software, connectors, etc) were initially developed, qualified, and field tested using a sensor rated for operation at 220 °C, the material for all the downhole components were selected for operation at 300 °C. So the remaining developments are to perform the characterization and qualification of a downhole sensor that will reliably operate at 250 °C and 300 °C.

In Q4 2008 a 90 day test was initiated to characterize the drift of the new sensor at 250 °C. Two of the three sensors drifted beyond the acceptance criteria of 15 PSI/year.

Figure8, Results of Initial Drift Test

Upon investigation, it was determined an insulating material that secures the pressure sensing elements had a glass transition temperature close to 250 °C. This material was changed and initial tests were promising. A second 120 day test to characterize the drift was started with sensors made with a new insulating material. The test completed mid May 2010.

Four of the six sensors passed the acceptance criteria of 15 PSI/year. The two that failed appeared to be caused by a mechanical or contamination issue and were removed from the test after 90 days. These units are currently under investigation to determine the cause of the failure. The graphs below show the pressure drift of the 4 good sensors. All four systems drifted under 15 PSI/year.

Figure9, Results of Final Drift Test

Currently working to increase the yield of the sensors when manufactured to minimize the cost of the system. At the end of the manufacturing process, each sensor is tested for 30 days at 250 °C to verify their drift performance is within specification. The current yield of sensors within specification is 77%.

System Qualification

The High Temperature ESP monitoring systems, including the surface card, were qualified according to established Schlumberger qualification test plans based on the appropriate mission profiles.

Listed below are some of the key tests performed. All tests were successful.

Motor/RTD Compatibility Test:

This test verified whether noise would be introduced to the temperature measurement if the RTD was tied to the motor end turns.

Signal Crosstalk Interference Test:

This test verified that there is no crosstalk interference with the sensor cable when the sensor cable is placed next to an ESP power cable. (2000 feet)

Figure 10, Picture of ESP power cable with signal cable attached

High Temperature Pressure Cycling Test:

This test verified the connection system, seals, and sensors held pressure AFTER the other EQ tests (Thermal Cycle, Shock, Vibe, Drop, and Cold Storage) were completed.

Figure 11, Pressure test profile

Accuracy tests for both Sapphire and Paine:

The chart below shows the results for two sapphire sensors and one Paine sensor. All three systems were in specification (± 10 PSI).

Figure 12, Accuracy Test Results

Note: The sapphire sensor (5397) in the above chart was removed the motor in the first field test installation and was in the well for 202 days with a maximum temperature of 216 °C. Using the original coefficients (was not re-calibrated), the sensor was within specification.

Field Test Results

As of April 2011, a total of 21 High Temperature ESP Monitoring systems have been installed. It is a mixture of RTD only Sapphire/RTD systems and Paine/RTD systems.

The distribution is shown in the table below.

	Number of Installs	Max Runtime (days)	System Runtime in Days	Ave Runtime as of 4/13/2011	Number Pulled
RTD Only	4	293	293, 220, 151, 115	195	
Sapphire	5	260	260, 253, 202 (Pulled), 178, 134	205	1 (motor failed)
Paine	12	188	3, 12, 25, 57, 58, 83, 99, 111, 113, 124, 161, 188	92	1 (motor failed)

The calculated survival probabilities are the following:

RTD only and Sapphire+RTD

Probability of Surviving 1 Year = 83.0% or better

Mean Life = 5.4 years or better

Sapphire+RTD

Probability of Surviving 1 Year = 72.2% or better

Mean Life = 3.1 years or better

Paine +RTD

Probability of Surviving 1 Year = No calculated. Will be when field test is completed.

Surface Card

Probability of Surviving 1 Year = 87.5% or better

Field Test Criteria and Results

The criterion for a successful field test has been met for the 220 °C and will be met for the 250 °C) at the end of Q2 2011 if the systems continue working.

To date, there has not been a monitoring system failure, including the surface Extreme Card, and the two pulled/stopped systems listed in the table was result of motor failures.

Below are some examples of field test results.

Field Test Example #1

Type: Sapphire

Install Date: 9/18/2009

Current Status: Pulled on 4/4/2010 due to motor failure, gauge system still working at that time.

Operational Days	Cable Length	Max DH Temperature	3rd Party Instruments	Firmware Version(s);
202 when pulled	668m	216C	None	1.375, 1.378

Figure 13, Start up of well.

Figure 14, Life of installation. (Data not collected for 2 months)

Field Test Example #2
 Type: Sapphire SN 7760
 Install Date: 10/12/2010
 Current Status: Still running.

Operational Days	Cable Length	Max DH Temperature	3rd Party Instruments	Firmware Version(s);
198 as of 4/30/2011	582 m	185C	Thermocouple and Bubble Tube	1.380, 1.382

Figure 15, Data from surface card.

Field Test Example #3
Type: Sapphire SN 7543
Install Date: 7/12/2010
Current Status: Still running.

Operational Days	Cable Length	Max DH Temperature	3rd Party Instruments	Firmware Version(s);
288 as of 4/30/2011	583 m	150C	Thermocouple and Bubble Tube	1.380, 1.382

Figure 16, Data from client SCADA (Bubble tube is client collaboration data) and surface card.

Field Test Example #4

Type: RTD only

Install Date: 11/7/2009

Current Status: Still running, but signal cable cut on 8/27/2010 due to wellhead power connector damaged. ESP still running and RTD in well.

Operational Days	Cable Length	Max DH Temperature	3rd Party Instruments	Firmware Version(s);
293	779m	185C	Thermocouple	1.375, 1.378

Figure 17, Measurements from surface card displayed to match client data below. (Firmware update in March)

Field Test Example #5
 Type: Paine SN 251072
 Install Date: 1/11/2011
 Current Status: Still running.

Operational Days	Cable Length	Max DH Temperature	3rd Party Instruments	Firmware Version(s);
109 as of 4/30/2011	670m	185C	None	1.382

Figure 18, Data from client SCADA (Bubble tube is client collaboration data) and surface card.

Financials

DOE Funding Level	Total project funding:	\$1.671M
	- DOE share:	\$1.254M (75%)
	- Cost share:	\$417K (25%)
Total Project Cost	Total project spend end of 2010:	\$1.710M
	- DOE share:	\$1.254K (73%)
	- Cost share:	\$456K* (27%)

*Does not include 2011 spending since project is not complete.

Future Direction

At the end of April 2011, the 220 °C system, which verifies the overall system operation, has been released within Schlumberger as a commercial product for sale to our clients by the field organization. At the end of Q2 2011, the 250 °C system will complete field test and also be released for sale to outside clients.

In order to be sold commercially within Schlumberger, the following items must be completed.

- Qualification Testing
- Field Testing
- Manufacturing/Production File
- Verification by Manufacturing organization that they can obtain the required parts and build the product
- Assembly Documentation and Test Programs
- Installation Manuals
- Operation Manuals
- Training material for application and sales engineers

With all these elements in place, only the following items remain to complete a system for operation up to 300 °C.

- Characterize and environmentally qualify 250 °C sensor at 300 °C
- Environmentally qualify new 7 conductor signal cable and downhole connector for operation at 300 °C