Permanent Downhole Monitoring

Optimizing production through a range of downhole permanent sensors and gauges that meet your specific production needs.
eProduction Solutions (eP), a Weatherford International company, provides solutions to increase production and lower lifting costs in green and brown fields. We deliver agile, well-supported products and services that foster innovative optimizing approaches for flowing wells and all forms of artificial lift. The software, hardware and completions solutions can stand-alone or integrate with the downhole gauge product offering to help you work better, smarter and faster.

Give us your unique application . . . and we’ll give you the right tool for the job.

We offer a complete range of downhole permanent sensors and gauges to address the wide range of well applications found in today’s modern production environments.

- Optical
- Quartz
- Silicon-on-insulator (SOI)

**Optical sensing systems** offer value for hostile well environments, particularly where well intervention is costly, if not altogether impossible. Optical sensing technology is a robust solution when dealing with commingled production from multiple zones, high-temperature/high pressure (HT/HP) and high-rate gas wells. Vibrations (V) from high-rate wells do not affect the performance of the sensors. Optical systems can integrate pressure and temperature with multiphase flow measurements, distributed temperature, downhole seismic and remote flow-control capabilities.

**Quartz and SOI** electronic downhole gauge systems offer flexibility while prioritizing overall well economics. Permanent monitoring of artificial lift applications, reservoir pressure monitoring, free-flowing wells, multi-zone applications and onshore and offshore platform wells are all typical candidates where temperatures and pressures are in the moderate to elevated range. Our quartz and electronic gauges have been continuously improved, through innovative engineering practices, to increase life expectancy while decreasing infant mortality.
Weatherford’s Permanent Downhole Gauges

Our solutions span simple to complex applications, from low producing assets to wells generating thousands of barrels per day and/or millions of cubic meters per day. Whether you need a single-point pressure/temperature (P/T) instrument to accentuate pump-off control or the ability to accurately measure temperature, pressure and flow in a HT/HP multizone well with optical sensing, we have the right solution.

For each unique application, we provide a fit-for-purpose system to fulfill the requirements. The common thread to all our solutions is the wide operating temperature range and the engineered-in reliability and accuracy demanded even in extreme environments. We use only best-in-class components to ensure repeatable quality for years of continuous service. Weatherford systems and solutions provide real value in all well phases of both brown and green fields.

In addition to downhole gauges, subsurface systems and sensors, we also offer robust and flexible instrumentation solutions for the accumulation, display, transmission and storage of acquired data. These surface systems can be stand-alone or compatible with legacy SCADA and communication systems. Downhole measurements can be part of a well or reservoir system or part of a comprehensive field optimization solution. The combination of downhole measurements with surface data and control systems enable better long-term management of the well, reservoir and field.
Typical Applications for Permanent Downhole Monitoring

Permanent downhole monitoring provides data that enable better decisions for improving production operations and reservoir management. Better decisions can accelerate production and increase ultimate recovery while reducing downtime. Temporary systems for making downhole measurements require well-interventions; but permanent systems remove the need for interventions reducing the related costs plus operational, production, safety and environmental risks associated with interventions.

Choosing the Right Product

The charts to the right depict typical production applications and the technology suggested for each. For a detailed review of your particular application and assistance with selecting the best-suited technology, contact a Weatherford representative.

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<th>Extended Reservoir Monitoring</th>
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Legend

● Recommended for this type application
○ Recommended for most applications of this type
■ Recommended for some applications of this type
□ Recommended for specific types of this application
▲ Not recommended for this application
## Pressure Monitoring Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Benefits</th>
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| Well Performance         | Real-time access to bottomhole pressure          | • Upper completion performance established  
• Gravel pack performance established  
• Monitoring for fines, scale or wax build-up  
• Wellbore hydraulic curves calibrated for optimizing gas lift  |
| Reservoir Pressure Control | Establish bottomhole flowing pressure above critical value while adjusting surface facilities production or injection rates | • Optimize production or injection rates  
• Monitor drawdown to reduce probability of sand production  
• Avoid long term damage to reservoir, improve recovery efficiency  
• Extend life of completion |
| History Matching         | Historical log of pressure data during lifetime of the asset | • Validation of reservoir models  
• Update or enhance reservoir understanding  
• Update recovery efficiency, estimate of reserves and lifetime of asset |
| Transient Well Testing   | Historical log of bottomhole pressure provides opportunity for transient analysis during planned or unplanned shut-in and drawdown of reservoir pressures | • Transient analysis without intervention  
• Early analysis of problem wells without waiting for planned intervention  
• Facilitates programming of regular reservoir surveillance to reduce severity or impact of problem wells  
• Eliminate deferred production associated with well intervention |
| Hydraulic Fracturing     | Real-time reservoir pressure during hydraulic fracturing operations | • Identify fracture initiation  
• Optimize fracture/stimulation duration  
• Optimize surface operations, duration and costs  
• Enhance safety for pressure control operations |
| Bottomhole Pressure Data | Real-time access to bottomhole pressure          | • Diagnostic pressure data during well intervention, leak-off tests, valve cycling, etc.  
• Enhance safety for pressure control operations  
• Correct fluid weights during remedial well operations  
• Subsurface pressure data for drilling and completion of future wells |
Optical P/T sensor–has a rugged glass microstructure featuring two Bragg gratings to measure strain associated with pressure and temperature. This optical tool boasts the industry’s highest mechanical shock and vibration survivability. Integration of the single-piece P/T transducer with a simple pressure housing delivers the smallest part-count and highest reliability for a P/T instrument. Immeasurable drift means that there are no concerns about absolute pressure and temperature measurement over the life of the field. This sensor is rated for environments to 347ºF (175ºC).

Optical sensors are widely used with high producing wells where workovers results in substantial production and revenue loss. Because of their resilient design, the sensors resist deterioration and consequently failure over the life of the well. Optical sensors also have the ability to deliver additional measurements–such as distributed and array temperature sensing, multiphase flow rates and seismic–on one multifiber cable.

eP quartz P/T gauges (ePQG™)–provide pressure and temperature by using a quartz transducer which incorporates a high-temperature hybrid design. The hybrid circuit is fully contained in a custom hermetic package for operation up to 392ºF (200ºC) with accelerated testing as high as 437ºF (225ºC). The packaged quartz gauge is temperature rated to 302ºF (150ºC). The robust package allows operation in extremely high shock environments. Quartz resonators use the inverse piezoelectric effect to induce the resonator to vibrate at its mechanical resonant frequency when electric fields are applied to its electrodes. An oscillator circuit supplies the power and allows the frequency to be measured.

Quartz gauges are commonly used to measure the changes in the reservoir. These measurements provide the reservoir engineer with information that can be used to update the reservoir model and ultimately base recovery operations.

mPOD³™ P/T/V gauges–provides measurement of downhole vibration in addition to pressure and temperature. This capability is useful in diagnosing artificial lift applications and free flowing wells.

The addition of vibration information in addition to pressure/temperature measurements provides an operator with another factor to determine existing and potential problems downhole. By measuring the vibration of artificial lift equipment, pumps can be right-sized to eliminate wear from vibrations. Production adjustments can reduce operational challenges in the pump before they become severe. By measuring vibration in flowing wells, well damage can be avoided by choking back the well when the flow rate is high enough to cause destructive-level vibrations.

mPOD²™ P/T gauges–provide multiple P/T gauge communication on a single conductor cable (multi-drop). The design incorporates an SOI transducer. The transducer converts a pressure into a change in resistance. The strain of the applied pressure is measured across an active four wire resistive bridge and the temperature is measured from a secondary of the main bridge. The gauge is rated for environments to 257ºF (125ºC).

One of the main applications of this gauge is to measure pressure and temperature above and below the artificial lift pumps. By providing accurate measurements, the operator is able to ascertain the problem of an underproducing well or challenging reservoir.
sPOD™ P/T gauges—are rated to temperatures of 257°F (125°C). The single point P/T SOI-type gauge transmits a square wave, current-pulsed output on the supply current (same conductor for power and signal). The square wave is counted and processed to generate the sampled downhole parameters, pressure and temperature. The gauge is fully compensated (calibrated) for increased accuracy.

This gauge is commonly used with artificial lift applications for low to moderate production assets. It provides information that allows operators to understand the changes occurring downhole.

Why Weatherford Permanent Downhole Monitoring?

**Options.** Rather than offer a single product for all downhole situations, we offer you a selection of fit-for-purpose solutions targeted to specific operational needs.

**Reliability.** Our subsurface gauges and surface control units consistently operate for periods far exceeding industry standards. A comprehensive series of environmental stress tests ensure stringent criteria are met for thermal shock, mechanical shock and thermal aging.

**Experience.** Our products and technology have benefited equipment operation and optimized production by limiting downtime on more than 15,000 wells. We have more than 25 years of experience with electronic downhole gauges and more than a decade of experience with optical sensing and intelligent well technologies. We have installed more than 100 optical systems to date, with a track record of innovation that includes many “world firsts” and award-winning technology and tools. We have achieved milestones of 1 million ft (305,000 m) of fiber-optic cable and 3 million ft (915,000 m) of optical fiber installed in wells. These achievements reflect more than one million cumulative in-well operating hours for our optical systems. Weatherford has installed over 2000 permanent monitoring systems with electronic gauges to date, resulting in more than fifty-six million cumulative in-well operating hours for our electronic monitoring systems.
Optical Sensing Systems

Optical systems can provide data for more efficient development and operation of simple and complex reservoirs. They offer clear advantages for certain well types and applications in terms of performance, reliability, cost and ease of installation. In fact, for multi-zone and other challenging well environments, optical systems deliver capabilities that no alternative technology can match.

The sensors themselves are all glass to withstand high temperatures, pressures and vibration. The glass is also immune to interference from local radio or electrical transmission sources. From a simple P/T optical gauge above-the-packer to horizontal, multizone sand screen completions, Weatherford provides an integrated optical architecture for virtually all life-of-asset measurements that you may need.

Typical Applications for Optical Systems

High Temperature/High Pressure
Optical sensing systems can withstand temperatures to 347°F (175°C). All the electronics are located at the surface and are more easily accessible for upgrades and maintenance; high-reliability, passive components remain downhole.

Pressure/Temperature Applications
In horizontal completions, P/T gauges are useful for defining drainhole production efficiency. When coupled with flow-control valves or inflow control devices, these gauges can ensure uniform production across a long horizontal section.

Production and Injection Profiling
Optical distributed temperature sensing (DTS) and array temperature sensing (ATS) systems may allow determination of production and injection profiles across the reservoir sections of horizontal, multilateral and multizone wells.
Well Startup Monitoring
Optical P/T sensors can be used effectively during well startups, not only to measure real-time reservoir pressure, but to manage initial drawdown. Our proprietary EPS Products software, such as the PanSystem and PanMesh programs, are used to create inference tests and pressure transient analysis to provide reservoir boundary information.

Downhole Flow Measurement
Real-time downhole flow measurement is critical for optimizing production from many of today’s complex well designs, including intelligent, multi-zone and multilateral completions. Data from a downhole flowmeter can be used to reduce or eliminate the need for surface well testing and the resulting operational, safety and environmental effects.

Optical flowmeters have no borehole restrictions or intrusions into the flow path. They are bidirectional, scalable to any pipe size and feature a control-line bypass for use in intelligent well systems. These flowmeters can be configured for single-, two- or three-phase flow and are applicable to production and injection wells.

Distributed Temperature Sensing
DTS allows monitoring of the thermal profile of the entire well, giving an indication of the production or injection profile across the reservoir sections and helping to identify flow anomalies, such as tubing or casing leaks, thief zones and flow obstructions. DTS has also been useful in determining completion effectiveness and the performance of gas lift valves.
Typical Applications for Optical Systems (continued)

Array/Multipoint Temperature Sensing
ATS is temperature profiling with multiple, discreet temperature sensors spaced apart along an area of interest in the wellbore. Multiple sensors are combined on a single fiber using optical multiplexing technology. The optical temperature sensors provide reliable, accurate and stable point temperature data, useful in measuring small production-induced thermal changes and/or can provide accurate reference points for DTS measurements.

Sand Control
Optical systems are adept for monitoring across perforated intervals and open-hole sections, deployed inside or outside the sand screen.

Water and Steam Breakthrough
Temperature profiling with DTS and/or ATS can help detect the intrusion of water, gas or steam in wellbores.

Multizone Completions
In multilateral completions and wells with commingled production from stacked reservoirs, optical flowmeter data can help resolve production allocations issues and determine productivity index for individual zones or the entire well.

Seismic Imaging and Monitoring
Permanent in-well seismic monitoring performs time-lapse vertical seismic profiling (VSP), cross-well seismic imaging and surface seismic calibration. In addition, seismic monitoring has been used to map fracture propagation during well stimulation. Recently, geoscientists have been listening to microseismic activity that is associated with injection, production, or subsidence—adding a new dimension to dynamic reservoir characterization. The seismic stations can be installed in a production well or injector or a nearby observation well.

Optical Cable
Our intelligent well systems integrate P/T, multiphase flow, distributed temperature and multi-station seismic capabilities on a single optical cable that can support multiple sensors. The number and type of sensors can be tailored to address specific downhole information requirements.

We currently offer two sizes of in-well optical cable: 1/4-inch and 1/8-inch. Both have been designed for maximum durability and longevity. Integration with precision, high-reliability optical connectors enable the cable to pass through packers, safety valves and other in-well equipment.
In keeping with the philosophy of providing fit-for-purpose solutions, we offer two fundamental types of implementations for subsea environments. The first option is an all-optical solution that involves eliminating all electronics from the seabed, where access can be difficult and costly. We install dedicated fiber in the umbilicals and cabling to connect the subsea wellhead, along with the in-well sensors, to the surface. The advantage of this implementation is that the complex opto-electronic instrumentation is located on the surface (in some cases, tens of kilometers away from the well), where it can be readily accessed for upgrades or repairs.

A second implementation solution requires installing the opto-electronic instrumentation in the subsea wellhead. This option is used when the required fiber or fibers are not available in the umbilical or subsea cabling, and can support P/T monitoring systems.

Fiber in the umbilical solutions is preferred and is available for all optical sensing systems. A key enabling component for optical subsea monitoring systems is the subsea-tree wet connector. Together with our industry partners, we provide wet-mate connector solutions for both vertical and horizontal subsea trees.

The Intelligent Screens™ system combines our optical sensors and Weatherford well screens—two highly effective and successful technologies—to enable safe, easy and permanent monitoring across perforated intervals and open-hole sections in sand-control completions.
Quartz Gauges (ePQG)

The ePQG quartz gauge transmits a binary frequency shift keyed (BFSK) signal transmission protocol. The transmission scheme allows for multiple ePQGs to be powered and communicate on the same, single-conductor cable. In addition to transmitting both pressure and temperature data, continuous monitoring of the gauges’ head voltage allows for basic diagnostics of cable integrity during the life of the installed equipment.

The micro-processor based design allows for monitoring of regulated gauge voltage and overall gauge current for analytical and operative performance monitoring.

Because frequency can be measured with greater precision than any other parameter, the sensor’s frequency output provides a high resolution, accurate pressure measurement.

Quartz is a perfectly elastic material, providing sensor stability and repeatability. The quartz resonator has a high Q (quality factor), which means that its vibration can be driven with very little electrical power.

Typical Applications for Quartz Gauges

High-Temperature/High-Pressure
Electronic systems are an economical solution when operators are faced with moderate to high P/T applications. Systems are rated to 302°F (150°C) to meet this demanding environment with exceptional accuracy and resolution.

Artificial Lift
Measure pressure and temperature data for automation and analysis needs, including gas lift, progressing cavity pumps (PCP) and more. With permanent monitoring proactive decisions are facilitated to reduce production downtime.

Pressure/Temperature Applications and Reservoir Pressure Monitoring
In horizontal or vertical applications, provision of in-well quartz P/T eliminates wireline intervention or production downtime for pressure surveys.

Zonal Isolation Monitoring and Pressure Transient Analysis
The ePQG provides robust longevity for a variety of applications, from basic land to complex offshore (dry) completions. Communications or commingling of the slightest amount can be detected with the accuracy and resolution of the ePQG quartz gauge.
SOI-Type Gauges

\textbf{mPOD}^2 and \textbf{mPOD}^3

Our \textbf{mPOD}^2 gauges transmit a proprietary protocol when addressed. Using an addressable scheme allows multiple digital sensors to communicate and be powered on the same, single-conductor cable. In addition to transmitting both pressure and temperature data, continuous monitoring of the sensor’s head voltage allows basic diagnostics of cable integrity throughout the life of the installed system.

These gauges are rated to environments of 257°F (125°C). One of the main applications of these gauges is measurement of pressure and temperature above and below an artificial lift pump. The accuracy of these measurements allows you to identify the problems of underproducing wells.

Our \textbf{mPOD}^3 gauges have all the features and technology of the \textbf{mPOD}^2 but incorporate the measurement of downhole vibration (Grms, frequency (G-force)). This capability is useful in diagnosing artificial lift applications and free flowing wells. Vibration information, in addition to P/T measurements, gives you yet another factor for determining problems and potential problems downhole. By measuring the vibration of artificial lift equipment, pumps can be right-sized to eliminate wear from vibrations. Production adjustments can reduce operational challenges in the pump before they become severe.

\textbf{sPOD} Single-Point SOI Gauge

Designed for permanent installed applications, our \textbf{sPOD} gauges maintain a minimum count of electronic components. The data is collected and processed with coefficients that are generated from a least mean squared, third-order polynomial fit calibration that is performed at Weatherford’s production optimization manufacturing and test facility. Calibration and verification testing ensures that the gauge adheres to and exceeds the accuracy and resolution specification determined for the design.

These gauges are rated to environments of 257°F (125°C). They transmit a square-wave, current-pulsed output on the supply current (same conductor for power and signal). The square wave is counted and processed to generate the sampled downhole parameters, pressure and temperature.

Typically used for artificial lift applications in low production wells, \textbf{sPOD} gauges are fully compensated (calibrated) for increased accuracy in low to moderate production wells. They provide the information you need to understand the changes occurring downhole.
Typical Applications for mPOD and sPOD Gauges

Artificial Lift
Monitoring a single P/T for pump efficiency or simple POC is a common application. Multiple P/Ts can be used for pump efficiency calculations, optimizing pumping rates and planning workovers.

Pressure/Temperature Applications, Reservoir Pressure Monitoring and Pressure Transient Analysis
Permanent electronic systems provide data that reduces the need for well intervention and the resulting production loss. Operators receive a continual data feed for the life of the well. Permanent reservoir monitoring provides continuous transient data without the inconvenience and loss of production experienced during well interventions.

Vibration (mPOD³ only)
The mPOD³ system allows determination of in-well vibration caused by flowing or artificially lifted wells. Understanding the severity of the in-well vibration characteristic enables the operator to fine-tune production, eliminating tubing wear or rod breaks.

Coal Bed Methane
Simple electronic gauges provide the ability to recover methane at optimum rates while maintaining positive well economics. They provide the data needed to facilitate proper drawdown of the fluid column while maintaining pump coverage.

Zonal Isolation Monitoring, Measurement Across the Reservoir and Array Multipoint Sensing
The mPOD² and mPOD³ use a unique addressing communication protocol allowing multiple gauges to be dropped on the same monoconductor, in-well cable. Zonal monitoring provides critical data to the operator to understand production contributions from isolated or commingled reservoirs.

Installation Accessories and Options
We carry a complete line of bare or encapsulated downhole cables, pneumatic cable spooling units, tool boxes, splice assemblies, junction boxes and other tools, accessories and procedures to facilitate installations and well completions in all environments, satisfying every application requirement. We also employ an experienced and highly-trained installation team.
Instrumentation, Data Interface and Communications

Optical and Quartz Gauge Interface
Weatherford offers a full line of reservoir monitoring systems (RMS) to fit the scale and complexity of your completion projects. There is an RMS surface system for interior or non air-conditioned, even harsh environments. These systems provide web-enabled accessibility for reading on demand.

Our basic RMS provides integrated information to operators from multiple optical tools. It can operate as a stand-alone data-acquisition, management, display and communication system or it can seamlessly interface with legacy SCADA, secure intranets, Internet or communication systems. With considerable local storage available, the RMS can hold an extensive amount of high frequency data. The system features a single shared network for Modbus, TCP/IP and OPC.

The system supports a simple P/T application to multiple P/T and DTS tools. The RMS, RMS-WH (wellhead), and RMS-WH-Q (quartz) can monitor up to six optical or electronic tools.

mPOD and sPOD Gauge WSMS Interface
The CS7X™ wellsite management system is an Internet-ready, modular, scalable system designed to provide real time process control and monitoring of oil and gas production facilities. The advantage of the CS7X well site management system (WSMS) is that it has been designed with built-in applications that minimize reconfiguration requirements. An integral web server supports direct viewing of process data using off-the-shelf browsers such as Microsoft® Internet Explorer or Netscape®. A flash file system supports FTP file transfer of system configuration and HTML files. Internal data Logging and IO capabilities are standard functionality of the WSMS.

sPOD Gauge Interface
A surface interface for the sPOD single-point digital gauge, the ePRO™ data process system has data storage and pressure-signal output that provides an ideal solution for single well applications. The system can output a pressure control signal to variable speed drive controllers to automate artificial lift equipment and be installed world-wide with no special considerations for venting or heating. The ePRO system offers compact size with ease-of-use. Designed for ruggedness, the system can be pole mounted or building enclosed.

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Single well ePRO interface unit for the sPOD gauge.

Control room RMS application model.

Well head/well site RMS model for desert or open environment.
Everything for the life cycle of your well . . . wherever you are.

Drilling, evaluation, completion, production and intervention. Weatherford’s global network of more than 30,000 people, operating from 730 service bases, 87 manufacturing facilities and 13 technology development and training facilities, in more than 100 countries, ensures in-country expertise and logistical support. You also have the reassurance of fit-for-purpose solutions, best practices, best services and best products.