Wellhead Pressure Interlock Protection

A White Paper Illustrating Current Advances in Well Protection and Control

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There are many pressure related issues of concern in petroleum well production. Both high and low pressure conditions are indications of problems that must be addressed to maintain well safety and performance. A flexible and reliable control system for pressure monitoring provides a failsafe interlock which prevents well operation under a variety of unsafe conditions.

Proper operation of a well requires the system be maintained within a specific pressure range. The range can vary from well to well, with offshore pressures typically higher than onshore. The concept remains the same – if pressure is too high, there is a risk of catastrophic failure. If pressure is too low, it may indicate clogging or catastrophic failure at the site.

Well control systems have evolved and become more sophisticated as technology and understanding have improved. Instrumentation is keeping pace and can now provide high integrity monitoring and protection with high efficiency features that increase system safety and reduce maintenance time and effort.

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Introduction

Advances in instrumentation technology are allowing greater well site safety and economy for oil and gas producers. Instruments have always been critical to well operation, now instrumentation and control systems have evolved to the point they can be an asset to operation, monitoring and maintenance of oil production. For example, pressure monitoring of a well flow line now provides failsafe safety interlocks as well as performance and prediction capabilities. In both onshore and offshore installations pressure measurement prevents some catastrophic failures, mitigates the effects of others and provides critical maintenance feedback.

Well failure protections include overpressure and leak/spill detection. Mitigation effects include well shutdown in catastrophic situations as well as Proof of Closure during mandatory shutdowns. A flexible, reliable monitoring and control system provides a failsafe interlock, preventing well operation under a variety of unsafe conditions. Industry concerns about spills and the associated cleanup costs and bureaucratic complications have reached new heights. Monitoring, prevention and mitigation efforts have gained in criticality in recent years.

Well operation and maintenance costs are being more closely monitored than ever before due to these influences. The days of routine scheduled maintenance and wholesale replacement of equipment are coming to an end as monitoring and control systems advance and allow more intelligent operations. As Producer's operational sophistication increases they demand greater performance and flexibility from their instrumentation and control systems.

The Problem

Well Site Issues

Chevron North America Exploration and Production Company (a division of Chevron U.S.A. Inc.) in Big Spring, Texas was searching for a reliable pressure monitoring solution for Central Permian, a difficult production field. This field has extraordinarily high paraffin content, which creates severe clogging issues with pressure instruments. Additionally, they wanted to create a pressure interlock safety system that was simple and provided protection for a variety of well conditions.

The two primary issues at the subject wells were clogging from paraffin buildup and the high costs of maintaining proper well protection. They were using traditional style pressure transmitters, featuring the common cavity-style sensor construction with female threads (see Appendix A). This type of sensor has an inaccessible pocket between the sensing diaphragm and the pressure port. Over time, this pocket filled with paraffin, clogging the sensor and preventing pressure measurement. The sensors could not be cleaned without damaging them irreparably, requiring the transmitters to be discarded and replaced every eight to 12 months.

In addition to the clogging issues, Chevron needed to develop a more foolproof interlock system. They required monitoring for high and low pressure safety conditions, an output that would effectively prevent operation in unsafe situations, and a rugged instrument that could survive the rigors of oil production in near-desert conditions. This would require an instrument with specific features to suit their needs.

The goals for this project included long-term operation, low maintenance needs, calibration and control flexibility, and rugged construction. Chevron collaborated with SOR Inc. to investigate alternatives. The two companies adapted a current pressure instrument to meet the needs of this problematic production field. During the process, they identified several other current and future control expansion needs of the oil production industry to be addressed in the same package.

Pressure Protection for Petroleum Well Sites

High pressure issues. Oil production sites operate within an ideal range of pressures. Pressure that spikes higher can indicate a problem but more typically will be a cause for concern about damage. A high pressure event can rupture the wellhead, flow line, a valve or other component, damaging a separator, compressor, etc.

Low pressure issues. On the flip side, low pressure can be an indication of a rupture and leak somewhere. Perhaps a component or gasket has failed, which would be detected by a drop in the flow line pressure. Or it may indicate a clogged or failed sensor. Today's oil production sites call for critical pressure monitoring right at the source, where it is coming out of the ground (onshore) or where it comes out of the water at the platform (offshore).

Whether a site features a positive pressure well pushing oil out of the ground or a pump drawing it up, the liquid in the flow line out of the wellhead is pressurized. In the event of a rupture, the pressure in that flow line will drop low enough to indicate a leak. That leak can be a pipe rupture due to corrosion, a gasket failure, some form of physical damage, or any number of other scenarios.

Sensor clogging as a result of high solids may also be indicated by a low pressure reading. High paraffin content in Texas oil fields tends to coagulate and can pack into the pressure port, eventually building up enough so that transmitter performance drops (see Appendix A). This condition is detected by a drop in the transmitter pressure reading. This can lead to replacing transmitters as often as twice a year on each well. Heavy sediment or high viscosity can also result in the same situation. Control systems cannot distinguish between a leak and clogged sensor, so both must be addressed as an on-site failure.

Proof of Closure. The previous issues are present in both onshore and offshore operations. An additional offshore issue involves the operation of the two shutoff valves. The Surface Safety Valve (SSV) controls the flow line on the platform. The Surface Controlled Subsurface Safety Valve (SCSSV) shuts down the well at the ocean floor. The SCSSV is expensive to install, maintain and even to operate. Whenever possible the well flow is controlled by the SSV, leaving the SCSSV for emergency operation only.

During a Hurricane Evacuation Remote Operation (HERO) event, operators must shut down production on a platform to prevent spills in the event of storm damage. This is done via remote operations from shore facilities through a digital communications network. Remote operation relies on proper feedback from the sensors monitoring operations. The well is shut down by closing the SSV on the platform, which stops oil from coming out of the ground.

Current practice relies on a valve position indicator reporting that the valve is completely closed. However, this does not indicate if the seals remain intact and whether oil has actually stopped flowing. In some notable past HERO events, oil has continued to flow at a low rate, leading to overflows and spills. Alternative Proof of Closure (POC) is necessary for reliable HERO safety. To achieve this, onshore practices can be adapted to offshore operations. Pressure monitoring of the flow line provides the protections listed above as well as POC. Operators need 100 percent assurance that the valve is shut and no oil is flowing. This is shown through an indication of no pressure downstream in the flow line.

Protection Scheme and Interlock Functionality

Pressure "window". The primary function of a "stick" pressure switch (pressure switch with transmitter capabilities) is interlock protection. The relay is used to shut down operations in the pressure conditions discussed above. Essentially, the instrument's solid-state relay features a window function where an operator can set high and low limits. For example, in onshore applications the relay may be set between 20 and 100 psi. Above or below that pressure window range, the relay de-energizes.

Typically, the relay is an interlock tied directly into the power on the main panel operating all equipment on the well. If that relay kicks off due to a low or high pressure condition, it shuts down power to all equipment, including the well pump. The interlock prevents the power from being reset remotely. That forces operators to go to the well site to inspect the problem in person, preventing inadvertent remote restart in an emergency condition.

To use this pressure "window", the user must determine the upper and lower safe pressure limits for the wellhead and flow lines. This represents the maximum safe system pressure and the lower pressure limit that would indicate a problem. The control system needs to be designed so that the interlock system is driven by this relay, only allowing well operation in the established safe pressure zone.

Control system design. By design, this pressure switch is tied to both the pump-off controller and the main panel. The pump-off controller may be fed by several indicators, including the pressure switch. If an operator should bypass the controller (i.e., due to maintenance, it is knocked out due to a power surge or lightning strike, or simply turned off for other reasons) the pump may continue to run without pump-off controller protection. Well protection must still be provided, so the pressure switch is also used as a cutoff for the main panel power. This provides pump and system protection in the absence of the pump-off controller.

In addition, the pressure switch serves as the primary well safety interlock device. If it detects unsafe pressure due to the noted issues, the switch can turn off the pump by cutting the power. Effectively, this pressure switch does not allow operators to circumvent the protection provided by the pump-off controller.

Likewise, with this pressure switch in the circuit, operators may attempt a manual restart even if an unsafe condition still exists. However, if pressure remains outside the safe zone, the system will not allow a restart, as power is still cut to the main control panel. Pressure levels must be within that safe zone to restart the well, whether through the pump controller or a manual restart. The switch is set to a normally open default, so even in the event of an instrument failure the pump will not operate until pressure interlock protection is reestablished.

Operational features. Other functional features are desirable to have at this pressure monitoring point as well. The pressure switch can also incorporate an analog 4-20mA signal with Modbus and Highway Addressable Remote Transducer (HART) communications. The analog signal typically offers local indication at the pump controller. The Modbus communications offers network functions reporting back to a central control system. HART is ideal for local maintenance (adjusting set points, pressure ranges, etc.).

During an offshore HERO event, well status is monitored via the Modbus communications network. In the event of a lost Modbus connection, it is critical to maintain protection at the pump site. The switch and communications must utilize independent outputs, so the switch relay can continue to provide interlock protection on loss of Modbus communications. Both components should be outputs from the parent instrument and function independently of the other. Because the switch resides locally, it continues providing interlock protection and ensuring local control.

Installation and Maintenance Needs

Retrofit in existing locations. It is also important for a well operator to be able to upgrade an instrument without re-plumbing. Maintaining the existing process connection size (typically ½-inch NPT) reduces retrofit time and costs. Replacing the traditional close nipple and NPT female process connection with a ½-inch NPT male flush mount diaphragm seal reduces threaded connections and installation costs.

Many well sites pack a large amount of piping into tight areas, leaving space at a premium. The slim profile of a stick transmitter, six inches long by 1 ½ inches in diameter, makes it easier to install. This small size allows easier hand and tool access, particularly on offshore platforms.

Maintenance. Maintenance represents another key consideration. Proper maintenance is key to consistent, reliable pressure protection. When buildup occurs due to high solids and/or viscosity, the sensor can clog. It is not feasible for an operator to dig into the pressure port with a screwdriver to remove the solids build-up, as even a nick in the diaphragm can render the instrument worthless (see Appendix A). This has led to the "throw-away transmitter" attitude and line of products from some instrument companies.

Alternatively, a flush mount diaphragm design eliminates the pockets where buildup can occur, improving maintenance. The sensor features a smooth, shiny, low tack surface which can be easily cleaned (see Appendix A). Operators just unthread the device and wipe it off, so no need for harsh abrasives or hard probes. Instead of discarding a clogged instrument, it can be quickly and easily cleaned and placed back into service.

Another maintenance consideration is damage from vibration and physical collisions. A traditional pressure switch or transmitter consists of a process connection tied to a short sensor, with a much larger electronics housing on top. This configuration is prone to problems with vibration and physical damage. When installed, the housing may experience a torque moment, letting the unit bounce and potentially breaking connectors inside the housing due to vibration. Alternatively, the slim profile of a stick instrument has an inherent low moment of inertia, with the center of gravity close to the process connection. As a result, this greatly reduces vibration effects, while a cast stainless steel housing resists physical damage.

Proposed Solution

Pressure Switch Functionality

"Window" capability critical. The proposed solution is a stick style pressure switch with transmitter and communications capabilities. To meet all safety requirements for onshore or offshore operations, the pressure switch relay serves as the critical output. As noted earlier, the "window" capability is the most important feature of this switch. It must be capable of establishing a window of safe operation for each site. The relay closes within this window of safe pressure range, opening and tripping the interlock when high or low pressure indicates an unsafe condition.

In essence, the relay (and associated interlock) is energized *only* within the safe zone. Any operation between the low and high pressure limits is acceptable. The system relies on the window's flexibility to accommodate the differences in oil wells. Most pressure switches do not have adjustable windows. Technically, this functionality is the same as dead band on a mechanical pressure switch, but much more capable.

Additionally, the pressure switch must be double-throw with failsafe capabilities. On a mechanical pressure switch, the relay will not reset in power loss situations, as it relies on a pressure change only to change state. An electronic switch has the capability to send a failure signal back via a solid state relay that defaults to "normally open" on power loss. True failsafe capability establishes a normally closed circuit as the normal operation condition. This allows an operator to set the failsafe, and in the event of lost power or a damaged instrument, the electronic switch defaults to normally open, regardless of the actual pressure, thus automatically engaging the interlock.

Safe operation. Under all circumstances, the switch or relay must be able to default to normally open in a power loss situation. A mechanical switch is driven by mechanical pressure, not an electrical signal indicating an open or closed state. This prevents the relay from defaulting to normally open on power loss. Typically, the pump on a well site can withstand a greater power surge than the control system. With a mechanical switch, a surge or lightning strike that takes out the control system but not the pump motor could allow that pump to continue running. The relay on an electronic switch will default to its failsafe state in the event of power loss, shutting off the pump as well.

Temperature compensation at the sensor is equally critical. Stick pressure instruments are hermetically sealed. The electronics housing is welded shut and completely sealed off from outside conditions. As temperatures change, the pressure inside the housing also changes. The instrument must compensate for temperature and pressure changes inside the housing itself to allow for accurate monitoring in all conditions.

Optional functionality. Monitoring and communication add-ons can extend the instrument's capabilities to meet a broader range of well site requirements and conditions. For example, the 4-20mA continuous output is typically used for local monitoring and trending. A local electronic display gives operators on-site visual access to flow line pressures. It may also be used for trending on the well, using a digital chart recorder on the control system to record the 4-20mA output.

HART communications supports operational efficiency. Operators may use this protocol to simplify field setup or to read a second output in multi-variable transmitters. In this situation, they employ HART by using their hand-held devices to access every feature in the instrument.

Modbus is a true digital communications protocol with a separate output signal at constant voltage. A digital network is cost effective, as it uses less electricity and wiring. Digital communications are also more stable than HART communications, making them well suited to offshore applications. During HERO events the digital communications network is used for remote on-shore control and operation.

Physical Packaging

Oil well operations, whether onshore or offshore, represent harsh environments with extreme temperatures, dirty conditions and often corrosive climates. Equipment must be environmentally durable and able to withstand physical abuse.

Instrument maintenance. For Chevron, the flush mount sensor was key to cutting costs by reducing maintenance and replacement needs. The ability to pull that flush mount sensor out and clean it off with a rag, versus removing a clogged instrument and replacing with a new one, became a huge cost savings. Any time that an operator has to break the conduit seal on an instrument, the seals must be replaced, increasing replacement costs. The flush mount sensor eliminates the need to replace the instrument or seals.

In addition, it was important for Chevron to eliminate the on-instrument LCD screen and push buttons, thereby preventing inadvertent changes by operators. Connecting a HART hand-held to make any changes forces them to stop and think about what they are doing.

Durability. The slim design of a stick instrument brings the Center of Gravity (COG) close to the process connection. This, combined with lower overall mass than a traditional transmitter, greatly reduces the opportunity for damage due to vibration. With a lower torque moment on the overall device and elimination of delicate display connectors, a stick device is inherently more survivable with compressors and other rotating/vibrating equipment. This design also reduces inherent damage due to shock and impact. The smaller profile functions basically like a length of pipe: there is nothing to catch (clothing, a tool, etc.), as no housing sections extend out from the profile.

Another durability advantage with a stick instrument is its heavy cast stainless steel enclosure. This is important for two reasons. First, aluminum is not an ideal choice in these extreme environments. Stainless steel provides natural corrosion resistance in harsh atmospheres, especially around seawater. Shifting from aluminum to stainless steel greatly increases corrosion resistance. Second, while material cost can raise dramatically with stainless steel, the smaller and simpler the casting, the lower the cost. The stick enclosure's simple stainless-steel casting achieves nearly the same cost as larger, more complex aluminum housings with much greater strength and corrosion resistance.

Future Direction & Long-Term Focus

Production Expansion

New technologies are making it possible to improve or revive existing oil fields. Deeper drilling, horizontal drilling and chemical extraction allow producers to tap reserves in old wells or achieve yields in areas previously not considered economically feasible. Some techniques call for the heating or dilution of crude oil reserves in extraction and transport, which can complicate pressure measurement. Driven by industry trends and the need for more reliable, lower cost instrumentation, these new conditions require operators to deal with greater viscosity and adhesion issues, which complicate many control system functions.

Economic Concerns

Today's cost of ownership typically falls into three main categories. First is the initial purchase price. As instrument companies strive to control their costs, the initial price is dropping with better production technology and an increased ability to create more focused designs. As a result, stick instruments are geared towards oil and gas production, versus a "one-size-fits-all" approach for multiple industries and applications. A device with standardized thread sizes and other features is easier to install or retrofit, further reducing installation time and cost.

In addition, the HART communications protocol allows for simplified calibration. Modern pressure devices can monitor a wide range of pressures with their range turn down features. This reduces inventory needs, as operators only need a minimal number of transmitter models to operate a wide range of wells. The instruments can be quickly calibrated to the appropriate pressure range on site.

The second cost of ownership involves operational and maintenance costs. Features such as the flush mount sensor design and communications flexibility make it possible to eliminate the "throw-away" attitude towards these expensive instruments. For example, rather than disposing of a $700 transmitter due to a plugged sensor, it makes more economic sense to pull it out, wipe the sensor off with a rag and reinstall it. Replacement of a traditional style transmitter would be considered a maintenance cost as compared to the time to clean a flush mount sensor.

The final cost of ownership is spill prevention and mitigation. This is paramount for any oil production site, as the cost of a spill outweighs the cost of the instrument by a large margin. This is far more true in offshore situations, where monitoring for SSV POC can prevent spills during shutdown conditions caused by overflowing on-board vessels or storm damage. Proper flow line pressure instrumentation helps prevent spills and promotes mitigation by shutting down operations quickly in the event of a leak or equipment failure.

Environmental Pressure

Environmental impact research is progressing as quickly as advances in oil and gas drilling technology, processing and transport are. As a result, producers, regulators and other decision-makers are gaining a much better understanding of the impacts of spills, along with more sophisticated ways to detect and track spills and leaks. Consequently, governments around the world are tightening up on spill and leak regulations. Detection is becoming much more sophisticated and regulation enforcement more prevalent. As a result, insurance companies continue to tighten up on spill/leak mitigation and interlock requirements. There are no regulations requiring POC yet in offshore HERO events. However, many industry experts expect its arrival soon as a critical safety prerequisite.

Instrumentation Flexibility

While these features are available on many different instruments, in today's demanding markets it is critical to package them together in a way that makes sense for the oil industry. Future advances in control technology will demand greater flexibility. Features such as digital communications enable better control now for making changes and adjustments in the future. They offer the capacity for instruments to keep pace with control schemes as they change and improve.

As one example, oil producers are examining ways they can reduce the physical number of devices utilized in a control circuit to improve the reliability of local control. The ability to combine a pressure switch, transmitter, Proportional Integral Derivative (PID) controller and control valve within a local loop from four down to two devices is gaining interest. Another technology advance is programmable stick instruments. Building a transmitter with a programmable SIM card incorporates the ability to load PID loop programming right into the instrument, eliminating the separate PID controller. The instrument in effect becomes an interlock sensor, monitor, pressure recorder, network node and PID controller all in one package.

Through quality of design and manufacturer advances in electronics, oil well operators are gaining finer control over well performance at lower costs. Consider innovations in transmitters just like advances in television over the last few decades. As the latest technology moves from analog to HDTV and even 3-D TV, likewise new instrumentation design is producing higher accuracy and greater flexibility that results in much more detailed information and control. In turn, this can further help users track and predict well performance and even modify the technology at the well itself.

Finally, Safety Instrumented Systems (SIS) design and testing provides for longer life and reliability. They ensure that critical components are operating safely and the process shuts down if an incident should occur. SIS systems are becoming very prevalent and a requirement for many applications in the oil and gas industry. This indicates the increasing safety consciousness and evolving protection requirements of the industry.

Resolution

Chevron and SOR collaborated to create the 805QS and its digital counterpart the 815PT. Both are stick pressure switches/transmitters built on the same platform. The 805QS has relay and analog outputs; the 815PT also includes digital Modbus and HART communications. An initial test unit was installed in the Central Permian oil field in August 2012, with sixty long-term trial units installed in September 2013. Chevron's is running a full 12-month field trial of the long-term instruments to evaluate their performance over a complete cycle of seasons.

At the time of this paper, all installed units have performed beyond satisfaction. The flush mount sensor appears to be not only preventing the loss of transmitters due to clogging, but actually extending the required maintenance cycle due. The units have lasted longer than the traditional instruments, without a single loss of measurement due to clogging.

It appears that removal of the cavity inherent in traditional pressure sensors has reduced the ability of the paraffin to build up. Maintenance may still be required, but the cycle time appears to be much longer. Actual monitoring performance has been flawless, with no loss of well protection to date. Chevron is confident that the new instruments, combined with the modified control scheme, will provide greatly enhanced monitoring and protection in this problematic production field.

Conclusion

High pressure, low pressure, proof of closure. In oil production it is critical to monitor all pressure conditions at the flow line as part of standard safe operating procedure. It is equally important to have independent interlock capabilities with methods to shut down the well in the event of a problem. Under any scenario, a reliable, cost-effective control scheme is paramount to ensuring a safe and high performance operation.

Minimizing cost of ownership and maximizing performance means incorporating technology with a high degree of control capabilities and versatility. Survivability in harsh environments and minimizing maintenance requirements are also key considerations. To that end, SOR and Chevron developed this stainless steel “stick” pressure switch/transmitter as an integral control component and long-term solution. Corrosion resistance, local switching capability, low maintenance and both Modbus and HART communications combine in an instrument specifically suited to wellhead pressure interlock protection.

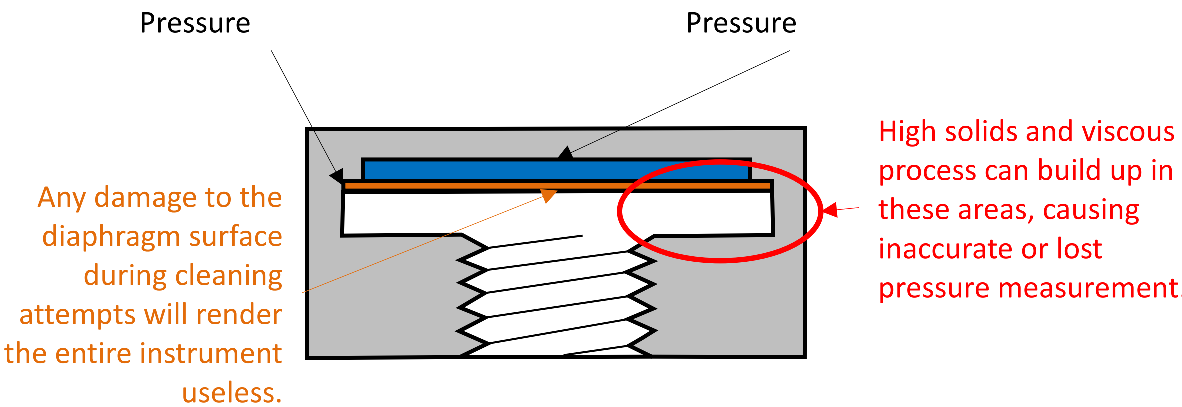
About the Authors

Russ Carlson is Engineering Manager at SOR Inc., responsible for sales, production and design engineering functions for a diverse industrial worldwide instrumentation line. SOR®, a global leader in the field of measurement and control, manufactures a wide variety of mechanical and electronic devices to measure and control pressure, level, temperature and flow.

LaQuayne Wright is Maintenance Planner, at the Vealmoor FMT, for Chevron North America Exploration and Production Company and is responsible for the planning, scheduling and maintenance of all surface equipment related to production operations. Chevron is one of the world's leading integrated energy companies. Chevron’s success is driven by the commitment to get results the right way—operating responsibly, executing with excellence, and by applying innovative technologies.

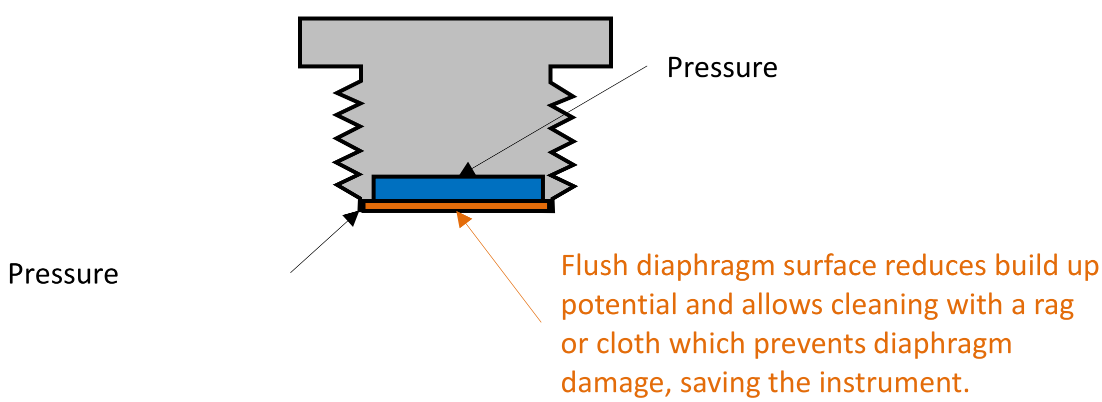
Appendix A – Pressure Port Comparison

The drawings below detail the difference between a traditional “Pocket Style” pressure sensor port and a “Flush Mount” design.



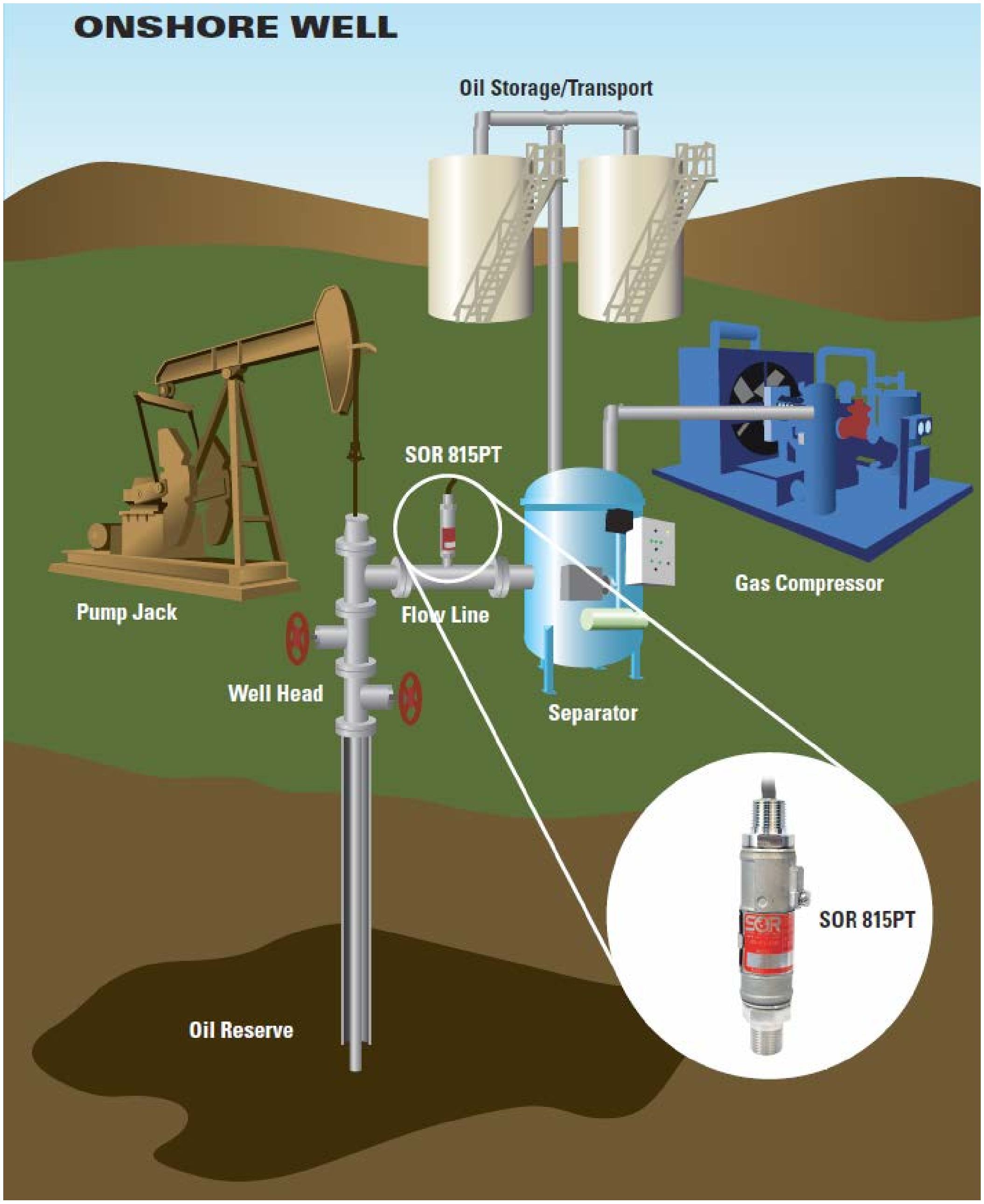
Traditional “Pocket” Style Pressure

“Flush Mount” Style Pressure



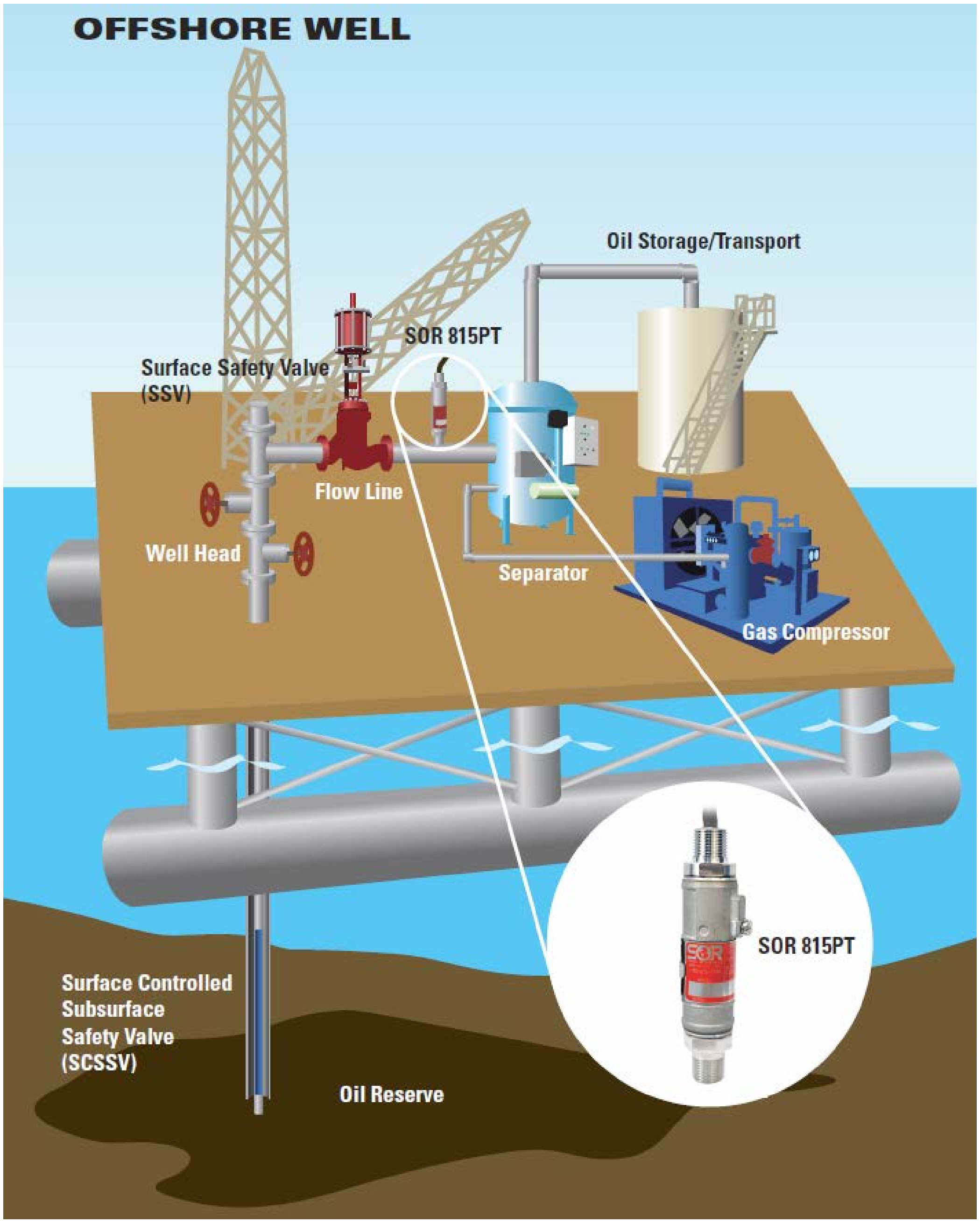
Appendix B – Typical Onshore Well Site

The illustration below shows the layout of a typical onshore oil well, noting the location of the wellhead pressure interlock instrument.



Appendix C – Typical Offshore Well Site

The illustration below shows the layout of a typical offshore oil well, noting the location of the wellhead pressure interlock instrument.



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