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# Subsea Well Testing at the Subsea Tree

Nathan Waldman, SPE, Data Retrieval Corp., Chris Fair, SPE, Data Retrieval Corp., Charlie Tyrrell, Oceaneering International, Inc., Rakesh Kumar, Shell



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## Abstract

Operators are often presented with a dilemma when installing instrumentation in a subsea well. Do they install permanent downhole gauges? If so, is there a back-up plan in the eventuality that the downhole gauge fails. In the past, when a downhole gauge on a subsea well failed, the back-up plan has either been to “fly blind” or to rely on low-accuracy measurements from subsea tree gauges or pipeline gauges (which can also fail). While tree or pipeline gauges may be adequate to determine if the well is flowing, they are rarely of sufficient accuracy and resolution to optimize production from the well. The need for high resolution, accurate pressure data is greatest in high permeability wells and in unconsolidated sandstones, where the production of sand can be catastrophic.

In 2001, a solution to this problem was developed. It allows an operator to temporarily install a highly accurate pressure recording system on the well in order to perform diagnostic tests on the well bore, completion and/or reservoir. This option is available to any subsea tree equipped with an Industry Standard “Hotstab” port. Typically, subsea trees are fitted with at least one female hotstab port conforming to ISO/CD 13628-8 enabling a remotely operated vehicle (ROV) to connect instrumentation specifically designed for this application. The ROV is then used to operate the isolation valves to allow well bore communication via the hotstab port. Once pressure communication with the well bore is established, diagnostic tests may begin.

The purpose of this paper is to introduce a mobile high-precision, high-accuracy pressure recorder for pressure transient testing at subsea well heads. First, the instrument and subsea tree specifications will be discussed. Then, a detailed procedure for installing this instrument on the subsea tree will be presented. Next, the issue of wellhead to bottomhole pressure conversion will be addressed. Results from field tests with the system will be presented. This new tool makes it possible to test subsea wells in which downhole gauges were not installed or where they have ceased to operate. The tool has also proven useful for pressure integrity tests when commissioning sub sea pipelines.

## Introduction

Accurate pressure versus flow rate data is as important to an engineer concerned with optimizing well production as an altimeter is to a pilot concerned with safety. Producing a reservoir at excessive rates risks collapse of the completion due to pressure drop exceeding the strength of the formation. Producing at reduced rates results in reduced cash flow.

The industry has recognized the importance of this trade-off by investing in frequent well testing. In the case of subsea wells, it is much more difficult and expensive to conduct pressure transient tests than it is from dry trees. Therefore downhole gauges are permanently installed at a cost that can exceed a million dollars per installation. However, experience has shown that the majority of these downhole gauges installations will fail, many in less than a year. When that happens, the operator has no way of knowing if he is in danger of collapsing his completion or is producing at an unnecessarily reduced rate. The high-precision subsea pressure recorder (SSPR) allows an engineer to acquire the data necessary to safely optimize well production.

## Subsea Pressure Recorder

The subsea pressure recorder (SSPR) is a self-powered device specifically designed for the acquisition of pressure transient data in the subsea environment. The device is housed in a subsea pressure vessel approx. 6 inches in diameter and 14 inches long. The system weighs approx. 40 pounds in air, 20 pounds in water, and is designed to operate in water depths up to 10,000 ft. Integral to the pressure vessel is the ISO/CD 13628-8 male Hotstab which is internally ported to the pressure transducer. The maximum allowable working pressure of the system is limited by the Industry Standard Hotstab to 10,000 psi.

The pressure transducer in the recorder utilizes dual quartz crystals, one for pressure measurement and one for thermal compensation of the pressure measurement. The transducer has an accuracy of 0.02% of full scale including corrections for thermal compensation, hysteresis and repeatability. Resolution is 0.01 psi. In addition to pressure, the recorder can also measure two additional variables such as seawater temperature or casing pressure.

The importance of high-quality, high-resolution data can be seen in Figure 1. In this plot, the low-resolution subsea tree gauge data is superimposed over data from the SSPR that has been converted to bottom-hole conditions. The low-resolution data from the tree gauge could not be used to determine that the pressure was dropping, much less reservoir permeability.

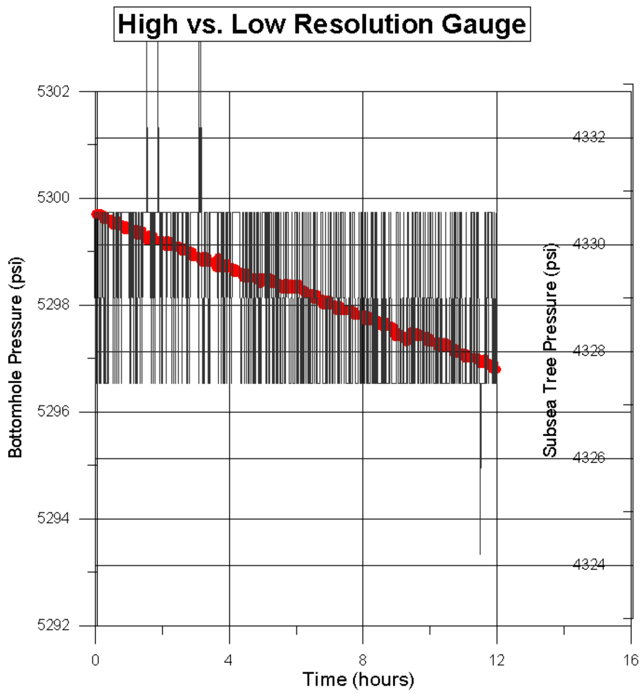


**Figure 1 – Pressure Data Resolution**

Pressures being sampled by the SSPR are recorded internally. The most recent pressure value can also be displayed on the integral LED readout for viewing with the ROV cameras. The recorded data are recovered after the recorder is retrieved to deck by the ROV. The recorder maximizes memory utilization by monitoring the rate of pressure change in the well and adjusting the rate of data storage to match.

The recorder is internally powered by three alkaline “D” cell batteries which can operate for up to two years or two million samples, whichever occurs first. This level of energy efficiency means that it is possible to leave the recorder connected to the subsea tree for the extended flow tests necessary for delineating reservoir limits.

## Installation

The high precision subsea pressure recorder (SSPR) is delivered to the wellhead by an ROV. When the ROV dives, the SSPR’s are usually stored in receptacles on the ROV Tether Management System (TMS) or ‘cage’. Figure 2 shows three SSPR’s installed on the cage of an ROV.
The ROV will also carry a methanol or glycol pump to be used for hydrate treatment and also to confirm that there is pressure integrity within the hotstab interface. The ROV may also carry a Torque Tool to operate the various isolation valves associated with the hotstab port on the tree.

**Figure 2 – SSPR’s on ROV Cage**

When the cage is at depth, the ROV leaves the cage and locates the worksite or tree. After inspecting the tree, the methanol/glycol pump assembly is connected to the tree at the hotstab port. The pump is then activated and pressure built-up against the isolation valves to confirm the integrity of the hotstab interface and associated seals.

The various isolation valves can then be opened to allow direct communication from the hotstab port to the well bore. The pump is then activated again and if no hydrates or blockages are present in the line, fluid will flow from the pump to the well bore. If fluids will not flow into the well, and the valves between the hot stab and the well bore are open, the blockage must be eliminated before the test can begin.

Once pressure communication with the well bore has been established and the pipework from the hotstab to the well bore has been dosed with Methanol or Glycol for hydrate mitigation, the isolation valves are closed and the pump assembly is detached. The SSPR can then be plugged into the hotstab port and the isolation valves re-opened to allow pressure communication to the SSPR. The ROV can monitor the LED readout to confirm that well bore pressure is being read. Figure 3 shows the SSPR installed on a subsea tree.

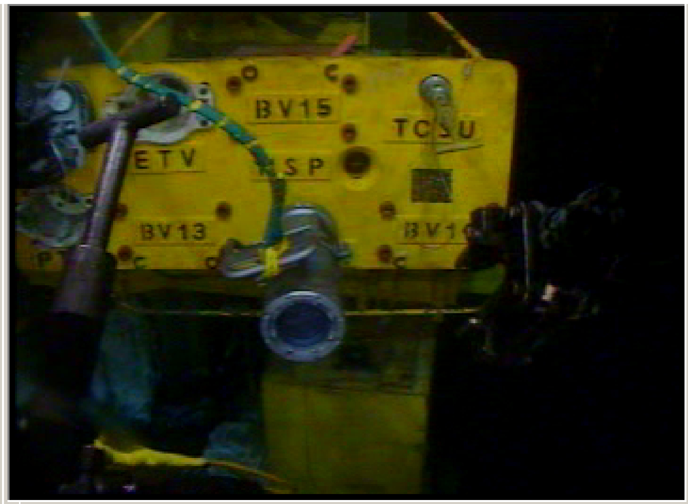


**FIGURE 3 – SSPR Rigged-Up on a Subsea Tree**

Upon completion of the test, the isolation valves are closed and the SSPR is unplugged and recovered to surface by the ROV. Once on deck, the stored data can be downloaded.

## Data Quality and Processing

The high precision subsea pressure recorder measures the wellhead pressure of the subsea well as opposed to the bottom hole pressure measured by permanently installed downhole gauges. The recovered wellhead data must then be converted to down hole or reservoir conditions before it is useful to the production engineer. The models for making these conversions have been developed over several years to the point where almost any well that continuously unloads all of its produced fluids can be tested from the tree.(1)

In spite of the extensive experience of pressure transient analysis from wellhead pressure measurements, some engineers remain skeptical of the ability of the models to fit their specific well. To satisfy those concerns, the operator should test his well with the SSPR while the downhole pressure gauge is still functioning. In that manner, any model tuning that may be necessary can take place before failure of the downhole gauge.

Wells should be screened to ensure that they are viable candidates. To be a good candidate, a well must produce naturally with a constant mass flow rate. Wells that slug or that have a gas/liquid interface between the subsea tree and the perforations will probably not yield valid results. In addition, well test procedures must consider the phase behavior of the fluids both in the well bore and the reservoir (2).

## Field Data – Case 1: Hydrotesting

The SSPR was first used for the pressure integrity test on commissioning a subsea pipeline in about 4,000 ft. of water. A custom built subsea pump was used to pressurize the pipeline with seawater taken from the same depth as the pipeline to eliminate the time that would have otherwise been required to allow the system to reach thermal equilibrium. Figure 4 not only shows that the pipeline contained the test pressure over the required time interval but the resolution of the pressure recorder was sufficient to show the pressure changes accompanying the six hour tidal cycle.

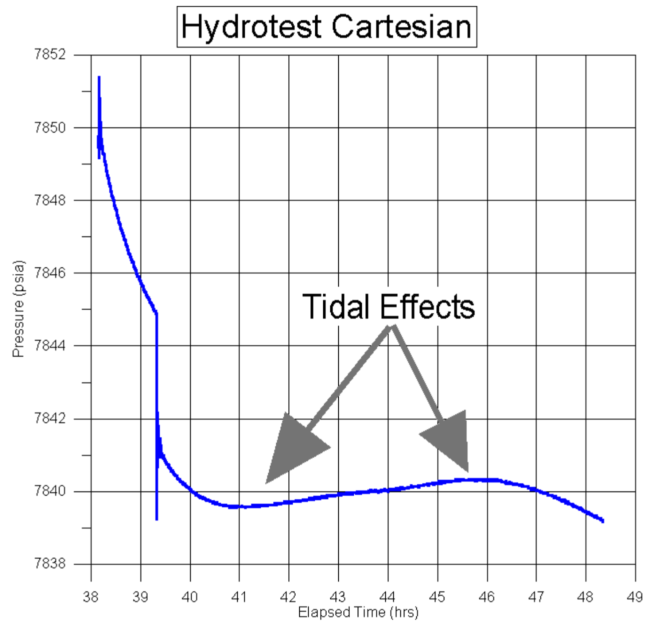


**Figure 4 - Hydrotest of a Subsea Pipeline**

## Field Data – Case 2: Well Testing

This well is a deepwater Gulf of Mexico turbidite sandstone. The subsea tree is in several thousand feet of water. The reservoir rock has a porosity of 29% and a water saturation of 20%. At the time of the test, the well was producing in excess of 20 MMscf/D with minimal condensate or water. After treating for hydrates, the SSPR was installed and a build-up test was performed on the well. The objective of the test was to determine the current reservoir pressure and to ascertain the reason for poor well productivity. These results were to be used to update and improve existing reservoir models, which were needed to justify further development of the field.

At the end of four days of data collection, the SSPR was retrieved from the subsea tree and returned to the surface, where the data was downloaded. The subsea tree pressures were then converted to downhole conditions and analyzed for skin, permeability, reservoir pressure and limits. Figure 5 shows a Cartesian plot of wellhead and bottomhole pressures. A semi-log plot and a derivative plot are shown in Figure 6 and Figure 7, respectively.

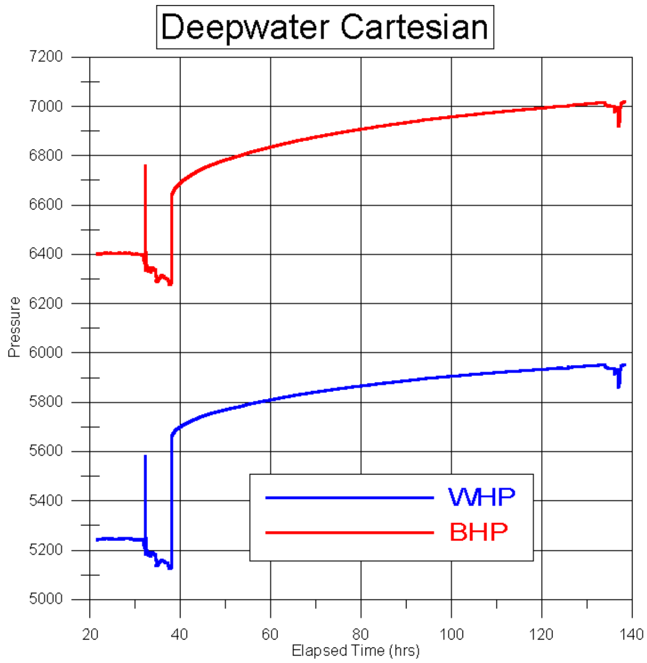


**Figure 5. Subsea Tree Pressure and BHP**

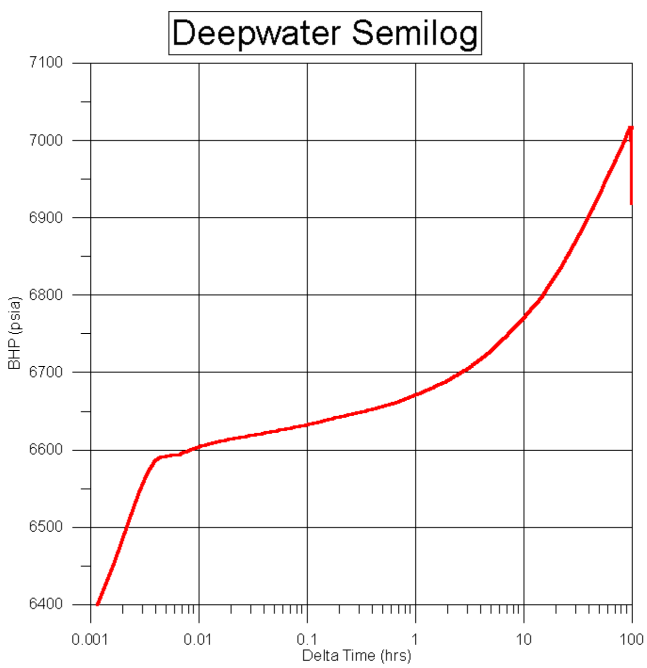


**Figure 6. Semi-log plot of BHP**

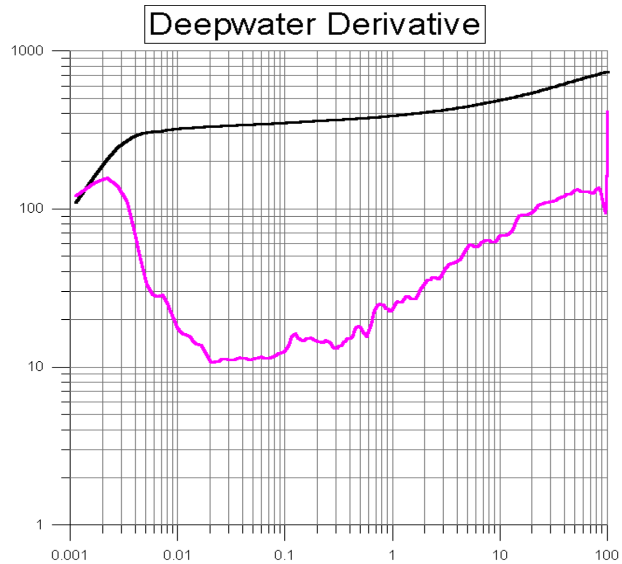


**Figure 7. Pressure Derivative Plot of BHP**

The pressure transient analysis indicated that the reason for the well's poor productivity was that the reservoir pressure was about 1,000 psi lower than expected and the permeability was only 25% of the anticipated value. These results permitted the generation of a more accurate reservoir model, which was used to justify further capital expenditure in the development of the field.

## Conclusions

The SSPR makes it possible to test subsea wells, where downhole gauges either were not installed, or where they have ceased to operate. Data acquired with the SSPR are comparable in both quality and accuracy to downhole gauges on candidate wells. Pressures recorded at the subsea tree with the SSPR can be readily converted to bottomhole pressures if there is a single-phase fluid from the subsea tree to the perforations or if the well is producing naturally with a constant mass flow rate. To build confidence in its use, the SSPR should be installed on wells with functioning downhole gauges. In this manner, it is possible to verify that the SSPR can be used for reservoir management and production optimization when the downhole permanent fails.

## References


1. Cullender, M.H. and Smith, R.V. (1956), "Practical Solution of Gas-Flow Equations for Wells and Pipelines with Large Temperature Gradients", *Trans.*, *AIME*, **207**, p281-287.
2. Fair, C., Cook, B., Brighton, T., Redman, M., and Newman, S., SPE 77701 "Gas/Condensate and Oil Well Testing - From the Surface," ATCE, San Antonio, Oct. 2002.