Abstract

Performing flowback operations in a vertical Wet Christmas tree (WCT-V) configuration requires three separate runs, of which two require a mobile offshore drilling unit (MODU). The first run is to land completion with tubing hanger (TH) from a MODU, the second run is to land the WCT-V on wire using a subsea equipment support vessel (SESV), and the third run performs the flowback operation to a MODU using an open water package. With a drive toward increasing the competitiveness of deepwater operations, a proposed solution was to have a single run using a MODU to both land the TH with completion and perform flowback operations. By combining the runs for completion installation and flowback, this becomes a valuable time- and cost-saving option.

The solution—based around the use of a subsea landing string incorporating a subsea test tree and associated electrohydraulic operating system—enables installation of the completion and flowback of the well in the same run and provides immediate validation of the well completion and dynamic reservoir characteristics. It also enables concurrent coil tubing operations that previously were only possible during the WCT-V installation phase of the well, requiring a MODU again.

This paper will explain the details of this solution implementation, the techniques used, system improvements, and it will provide an overview of the kind of jobs performed in this configuration.

Keywords: Subsea landing string, WCT-V, christmas tree, flowback, deepwater, completions, SESV
1. Introduction

Flowing back after landing the completion using a subsea landing string system that incorporates a subsea test tree and associated operating system is traditionally accepted in horizontal Wet Christmas tree (WCT-H) operations, where a lack of inline valves within the WCT-H makes the subsea test tree a necessity.

Historically, Petrobras has favored the WCT-V configuration using the Drill Pipe Riser (DPR) and has performed flowback in open water configuration with the WCT-V installed. The DPR system was revolutionary at inception in 1999 and, as noted by Fonvielle et al., enabled the petroleum industry to use the DPR to run the TH as well as install and retrieve the WCT-V in open water. However, this required the use of a MODU to both land the TH as well as perform a flowback after WCT-V installation, as shown in Fig. 1. The leasing cost of a deepwater MODU can be USD250,000–500,000 per day Moreover, a DPR operation from a MODU would require the tripping of pipe even for installation and retrieval of the WCT-V, which would add to the time required to complete a well and obtain first oil.

![Figure 1. Current DPR operations with flowback in WCT-V mode.](image)

BOP—blow-out preventer; COP—completions; TCP-tubing conveyed perforations

Our challenge was to reduce the time for completing a well, while at the same time reduce cost and dependence on a MODU. We noted that it took an average of 10 days to run the WCT-V and the tree cap (TC) from a MODU, as shown in Fig. 2.

![Figure 2. Santos Basin completions installation time (hours) baseline analysis.](image)
On the basis of this analysis, the solution proposed (Fig. 3) included the use of a subsea test tree with electrohydraulic operating system to land the completion, stimulate the well, and perform the flowback in the same run, followed by WCT-V installation from a SESV, with a total rig time savings of 10 days. This was made possible by leveraging the significant technological improvements in the deepwater industry since the advent of the DPR system.

![Diagram of subsea landing string operations with flowback in the TH mode.](image)

**Figure 3. Proposed subsea landing string operations with flowback in the TH mode.**

This solution came with the following benefits:

- **Improved rig efficiency**
  - The MODU can perform all steps required to install the completion and perform the production test (PT) without pulling the drilling blowout preventer (BOP). Once the MODU pulls the drilling BOP, it can depart, and all other operations can be performed by a SESV or smaller rig, resulting in reduction of MODU time by > 10 days per well.
  - Batch operations can be enabled, wherein the work sequence for completion installation can be split into operations requiring a drilling BOP and activities for installation of subsea equipment. A MODU with a drilling BOP and well test setup can complete those operations from start to finish without any rig movement or unnecessary pipe runs for subsea equipment, improving rig utilization.

- **Reduced completion costs**
  - Single-rig completion saves on logistics, rig fuel, number of personnel trips, anchor handling time, etc.
  - The need for DPR open sea mode can be eliminated, as the proposed solution enables the flowback with a subsea landing string in a TH mode, and the Christmas tree is installed on wire using an SESV.
  - If DPR open sea mode is run from a rig for Christmas tree installation, the need for a high-specification DPR pipe with high H2S and CO2 requirements is avoided. The proposed solution reduces the cost and complexity of flowback by transferring to the requirements of in-riser mode, and open water pipe can now be of a lower-specification or standard drillpipe.

- **Assured completions**
  - All completions can have a flowback while a MODU is in place to perform rework if necessary.
  - The functionality of intelligent completions can be verified early, in flowing conditions.
  - The integrity of gravel pack can be verified immediately after installation.
  - The integrity of gauges, safety valves, and other completions accessories can be tested and verified immediately.

- **Improved well productivity**
  - Formation damage can be prevented, with no well suspension required between completion and flowback.
Stimulation can be performed in the same run and without coiled tubing.
Coiled tubing operations can be performed for well intervention on the basis of production test of the well while flowing back.

2. Background – Subsea Landing String System

Large-bore subsea landing strings have a successful track record of more than 16 years, although most of the utilization is concentrated in WCT-H configurations. In this project, a subsea landing string interfaces with the subsea equipment as part of a WCT-V configuration. This provides the capability for dual pressure-sealing barriers, from the production bore to annulus and the annulus to the environment. The production bore contains two hydraulically operated valves that can be closed while the well is flowing as an emergency shut-off device, one of which is capable of shearing coiled tubing. A controlled disconnect latch mechanism is positioned above the shut-off valves and below an upper riser fluid retainer valve. The latch can be used to separate the landing string from the subsea test tree, allowing the BOP shear rams an unobstructed closure.

The subsea landing string can mate with the tubing hanger running tool (THRT) to hydraulically control the THRT as well as provide pass-through controls and electrical monitoring for the completion. The landing string bore will provide full bore access through to the top of the THRT for passage of plugs, retrieval tools, and flowback from the reservoir.

The electrohydraulic operating system allows the operator full control of the subsea test tree, TH, and THRT as well as the option to control completions functions, such as the surface-controlled subsurface safety valve. The system has programmable emergency shut down (ESD) and emergency quick disconnect (EQD) levels, which can be configured to shut in a well and unlatch from the subsea test tree in 15 sec.

The subsea test tree and the electrohydraulic operating system are the technologies that enable flowback in the TH mode. In conjunction with the SESV, the proposed solution generates significant savings in MODU time and logistics cost and improves asset utilization in comparison with the DPR method. As shown in Fig. 4, flowback in TH mode with a SESV for Christmas tree installation can complete three wells, on average, in the same time needed to complete two wells and flowback in DPR mode.

3. Methods that Enable Flowback in TH Mode with WCT-V Configuration

Performing flowback in TH mode with WCT-V configuration has many advantages; however, implementation comes with additional requirements for the subsea landing string system, which are not needed in WCT-H configuration, such as...
1. Controlled access to completions annulus to perform TH seal test as well as spot or displace fluids in annulus
2. Hydraulic control of completions (intelligent completions, safety valves, and chemical injection mandrels) through the subsea landing string system
3. Real-time, permanent downhole gauge (PDG) monitoring throughout the job, enabled by the subsea landing system

Additionally, the client required a modular solution for the systems to provide the flexibility to work across various MODUs with various different THRTs and a limited set of subsea test tree tools. This created the challenge to fit the subsea landing string across various kinds of BOPs.

3.1. Annulus access valve
An annulus access valve (AAV) had to be designed, qualified, and deployed to overcome the first challenge. The valve would confirm landing of the TH, allow test of the upper seals of the TH, and enable displacement of fluid through the completions annulus, allowing spotting of stimulations fluids at the reservoir. With the DPR method, it’s difficult to obtain a successful low-pressure test due to the volume of the fluid in the umbilical coming from the surface. In this case, the electrohydraulic system monitors pressure of this test at source in real time, providing confirmation of TH landing and seal integrity with certainty.

As a de-risking measure, the AAV was based on a proven technology, that is, the pump-through flapper safety valve (PFSV) which is a 3-1/8-in OD, 1-1/8-in ID, 60-in long flapper valve. With the initial design based on an existing mechanism, the product development cycle was shortened. From the initial design, the tool was customized to fit the space as well as client requirements of a 3-in OD, 1-in ID and 12.8-in long working envelope.

Figure 5. Annulus access valve installed in the TH-running tool adapter.

Another technique to reduce the product development cycle time was to conduct a change point analysis on the original proven PFSV design and perform application-specific validation testing to ensure it was fit for purpose for a deepwater in-riser application. The testing followed the proprietary qualification process for subsea pressure and temperature profile—cycling the valve from 32 to 70 degF at an absolute pressure of 17,500 psi, and qualifying the valve
successfully for five runs without a need to redress. The rigorous application-specific qualification testing on a proven technology was the key element that enabled release of this valve for field use within six months of identifying the requirements.

3.2 Hydraulic control of all completions functions through the subsea test tree

With subsea test trees primarily operating in WCT-H configurations, their design generally has a lesser number of hydraulic feed-through ports. This is because, in WCT-H configuration, the control of the completions is through the intervention workover control system of the WCT-H after landing of the TH.

In WCT-V configurations, the entire control of the completion throughout the duration of the job is through the subsea test tree. This created a unique challenge for the implementation of the solution because each module of the subsea test tree had to be revisited, and several modules of the subsea test tree had to be modified to provide increased hydraulic conduits for the additional functions that needed to be controlled. In addition, innovative solutions, such as pilot-operated valves for additional multiplexing of lines had to be devised to fulfill the completions control requirement in WCT-V mode.

3.3 Real-time permanent downhole gauge monitoring through the subsea test tree

Since control of the completion is always through the subsea test tree, it becomes imperative to provide a reliable means for real-time communication to the permanent downhole gauges, which are installed as part of the completions.

![Figure 6. Permanent downhole gauge conduit through the subsea test tree.](image)

With an eye towards reliability, the approach chosen for this challenge, was to maintain single cable passing through the electrical ports of entire string (except the disconnect point, and the control system connection to the subsea test tree, which had wet-mate connectors due to functional requirements). Additionally, as shown in Figure 6., custom subsea termination joints rated up to 17,500 psi were designed and deployed through the string, to offer a point for troubleshooting communication issues for the field user.

3.4 Flexibility of deployment across rigs

Client required a modular solution for the systems, providing the flexibility to work in 34 different rigs with 4 unique THRT interfaces, summing up to 136 possible combinations. To streamline this challenge, we narrowed down the
MODUs into 4 groups on the basis of BOP similarities and standardized the project-specific equipment into 37 different pieces to be designed and manufactured.

![Diagram of MODUs](image)

**Figure 7. Common Reference Point for accommodating different THRT interfaces.**

Additionally, for the flexibility to work with four unique THRT interfaces, each with its own stick-up height, new adapters were designed that would allow us to establish a common single datum among all interfaces. These adapters were unique to each THRT interface, enabling the subsea landing string to be re-used on a rig with just a swap of the bottom adapter. This unique concept rendered a subsea landing string usable for multiple jobs on the same rig, each with different THRT interfaces, resulting in an extreme adaptability of the systems.

### 4. Results

As of 2015, nine completions have been deployed successfully using this system in Brazil, of which three were in the top-ten list of the fastest completions deployed by the client, including WCT-V installations.

![Bar chart of TOP 10 intelligent completions in Santos Basin](image)

**Figure 8. Four wells in the top-10 fastest intelligent completions deployed by client used the proposed solution.**
Among the six intelligent completions deployed using this system, one of them was the fastest intelligent well completions deployed by the client, while four of them were in the top-ten fastest intelligent completions deployment. The fastest intelligent completions deployed with this system, took only 29.8 days (the first one ever to take less than 30 days), including the installation of the WCT-V using a SESV. This is almost 10 days less than the fastest completions deployment using the DPR system, achieving the initial goal of 10 days of rig-time savings. On an average, the 9 jobs performed using this system took 42 days to finish (normalized to remove outliers in data caused by operational issues).

Additionally, this system was used to deploy even three simple completions, and one of them was in the top-ten fastest completions ever deployed by the client in the Santos Basin.

![Image](image.jpg)

Figure 9: First Deployment of Subsea Test Tree as part of this project.

5. Future Improvements

During operations, various avenues for improvement were identified, some of which are listed here:

- The AAV—a multi-purpose valve in WCT-V configuration—needs an improved design to increase debris tolerance as well as needs independent opening and closing control lines for improved flexibility during operations.
- Introduction of an instrumentation module which continually records and transmits real-time information (e.g., tension, orientation, mechanical loads, pressure, and temperature). The availability of this information could address the expected requirements in future global standards governing subsea landing string systems.
- Additionally, as Moreira et al. noted, “The weak point is the control umbilical and related equipment such as hang-off equipment and clamps, which showed problems deemed to be critical in 3000 m. Control umbilical requires careful handling, particularly in the tubing hanger mode when it has to be deployed inside the marine riser.” The proposed future solution to improve this could be a control system that is completely without the umbilical, which will improve the performance of this system by an order of magnitude.

6. Conclusions

The use of a subsea landing string incorporating a subsea test tree and electrohydraulic operating system is a competitive solution for deepwater completions in WCT-V configuration. Major benefits include reduction in MODU time per well as well as faster Christmas tree deployment. Operational challenges for annulus access, additional control lines, and permanent downhole gauge read-back can be addressed using a well-engineered approach. Additionally, establishment of a common datum reference, optimizes the number of project-specific equipment required, while still maintaining operational flexibility.
With the increasing need to reduce deepwater operational costs, the use of a subsea landing string with an electrohydraulic operating system in WCT-V configuration to perform flowback operations will continue to rise.

8. References