

Sub-Surface Safety Systems for CT Deployed ESP's

Craig M^cK Webster and Juan J. Tovar D., Innovative Engineering Systems Ltd.

Abstract

Coiled Tubing (CT) completions have developed significantly in the last 5 years, most of the individual components have evolved from well intervention technology; both wireline and CT systems. Safety systems in particular continue to utilise conventional completion technology, particularly for components such as downhole safety valves. While mostly successful, this approach suffers from the inherent limitations associated with the existing systems. A new generation of purpose designed and build safety systems have been developed for CT completions, particularly for wells using (Electrical Submersible Pumps) (ESPs). A detailed review of the deployment requirements both in safety and operational terms was used as the base of design, previous industry experience was also considered.

The new systems perform four (4) main functions: isolation, circulation, cable cutting and system release.

For CT ESPs the system can be configured to include the four main functions mentioned above, a formation isolation component which ensures that, once the pump is shut down, fluids in the casing will not rush back into the reservoir potentially causing damage to the ESP. Depending on the type of completion a circulating sub and a mechanical release system are placed at the interface between the CT string and the ESP assembly. These two components allow well neutralisation and eventual release from the ESP assembly leaving a clean Bottom Hole Assembly (BHA) with the reservoir isolated from the wellbore. In the process of releasing from the BHA, the cutting function is activated ensuring that retrieval of the ESP assembly will not be impaired by the existence of a long section of electrical power cable above the fishing neck. This paper describes these systems and their main characteristics in detail.

Background

As part of the development of an alternative deployed ESP system using CT with ESP cable on the inside^[1], it was necessary to develop suitable safety systems for its deployment. Two separate systems were designed, manufactured and tested which provide a number of functions developed to overcome limitations in existing equipment^[2]. The systems include a circulation and release sub, which is placed at the top of the BHA completion, while a flow control and isolation valve is located above the pump. The functions of these two components are listed below

- Allow circulation of fluids from the CT into the casing annulus
- Release from the BHA
- Ensure a cleanly exposed fishing neck for fishing operations
- Prevent pump/formation damage as a result of flow back during pump shutdown
- Enable start-up of the pump/motor with sediments lying on the valve

In order to fully understand the functioning of the components, a review of the overall completion design is given in the following paragraphs; a general assembly schematic is shown in Figure 1 below.

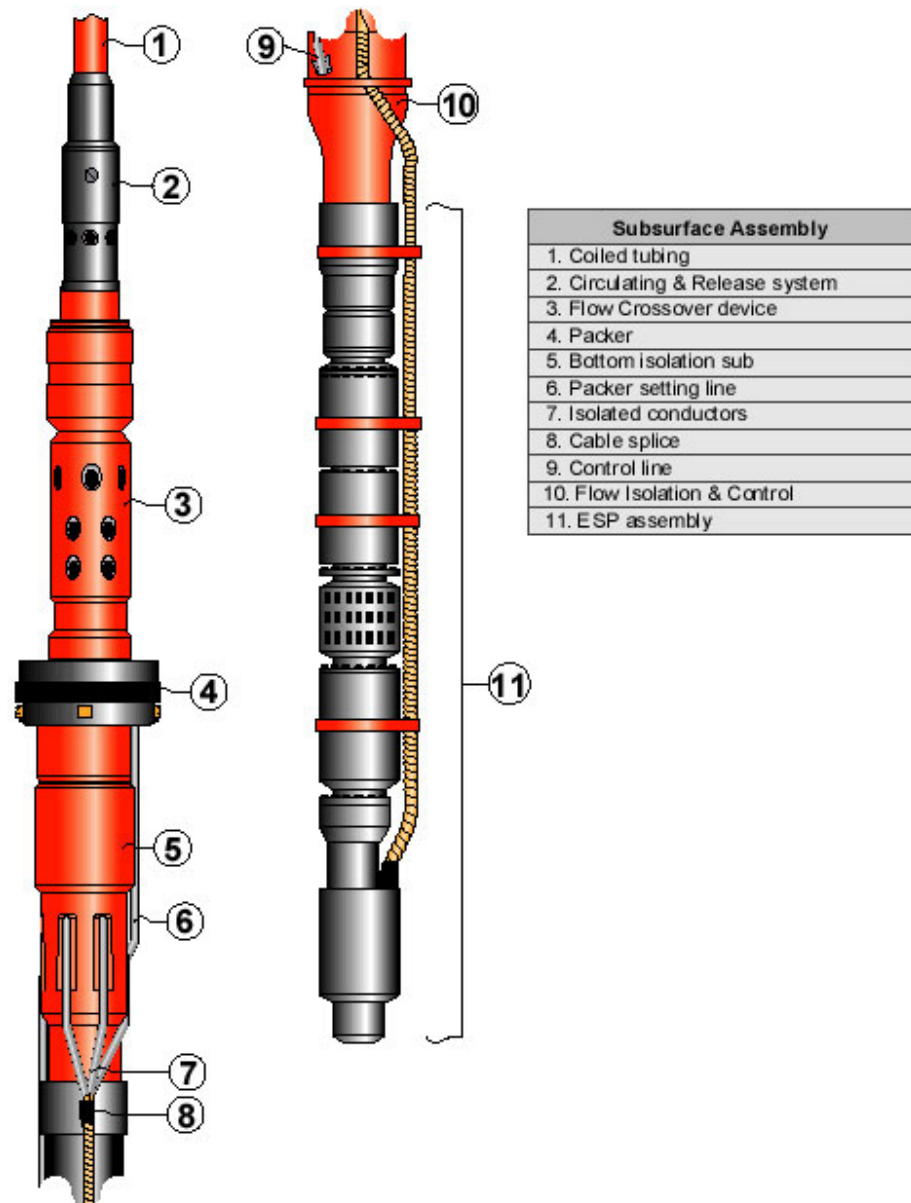


Figure 1 – ReELIFT® Series 'C' – BHA

The BHA is designed to allow the deployment and retrieval of electrical submersible pumps on a CT string. The cable is internal to the CT, and is then passed through a number of components that provide electrical isolation, allowing the crossover of the produced fluids into the annulus above the packer. The ESP assembly is of the conventional type, with the motor located below the pump.

The cable passes through the circulation and release sub, and is then split into its individual conductors and sealed with a proprietary sealing compound. Cables are then passed through the discharge head, and the packer using a steel isolation stem, and again isolated as they pass into the casing annulus below the packer. Below the lower cable isolation sub is pup joint and the flow control and isolation device.

Circulation and Release – CiR™

This component can allow circulation of fluids to kill the well or carry out workover operations. Circulation rates are from 0.5 to 1.5 bls/min, and a minimum of 0.5 bbls /min are required to activate the tool. Nozzles have been provided on the circulation ports to maintain the pressure drop across the tool while circulating. The tool allows fail-safe release from the BHA, and a cable cutting mechanism that leaves a clean fishing neck for retrieval. The tool is hydraulically operated through the CT. The assembled tool is shown in figure 2 below.



Figure 2 – Assembled CiR Tool

One of the concerns with similar tools is the premature release from the BHA. A dual safety system is used. Should excess pressure be applied inside the CT during running in of the completion, or after the packer has been set, the pressure must first overcome a set of shear pins, which would give a positive pressure indication on surface. If continued pressure is applied, the tool will only allow circulation into the casing annulus and not release. In order to release from the tool, it is necessary to circulate for a second time whilst pulling on the CT string.

Problems have also been encountered during fishing operations due to cable extending from the fishing neck^[3], resulting in prolonged and costly fishing operations. To overcome this particular problem, a shearing mechanism has been included which remain flush with the ID of the housing. As the tool is

pulled during release, the cable conductors are cut. The cutters remain flush with the internal wall of the release sub until such time as a release procedure is required. It should be noted that the cutters are not intended to cut the cable, but only to provide a definite breaking point, such that no cable protrudes from the top of the fishneck.

These functions provide a safe and efficient means of running, circulating and retrieving the BHA / CT assemblies from these types of completions, ensuring that the BHA can be run without accidental disconnect and leaving a clean fishing neck upon retrieval. Details of the circulation and release sub specifications are shown in Table 1 below.

Specification	Value	Remarks
Max OD	5.75 in	
Length	93.75 in	
Max Tensile Load	100,000 lbs	
Circulation Rate	0.5 – 1.5 gal/min	$\Delta P \leq 800$ psi
Release Load	2000 lbs	During Circulation
Activation Pressure	600 psi	2 Cycles

Table 1 – CiR™ Specifications

CiR™ – Testing

In order to ensure coherence with design and proper function of the tool, various forms of testing were carried out to determine the critical operating parameters against those for which the tool was designed. The testing program included the following:

- Pressure integrity
- Functioning
- Release
- Circulation
- Cable cutting

The pressure integrity of the tool was tested to a differential pressure of 5000 psi. Test plugs were used during the test to prevent the tool from cycling. Function testing of the tool was carried out to ensure the correct operation of the springs, and tool cycling. A high spring rate was utilised in order to overcome the ‘stiction’ forces incurred by the O-rings.

Testing of the release mechanism was carried out in two stages. The first test determined the overall safe tensile load of the tool, in order to ensure that retrieval of the packer could be achieved. The test was carried out to ensure that accidental release would not occur during running in or pulling of the packer. The second test, with the lock sleeve in the release position, determined that the release load on the collet was within the designed parameters. Calculations had shown that release of the collet would occur at 2400 lbs of pull. The pull test was repeated with cable inserted inside the sub, in order to test the shearing mechanism. As predicted the teeth provided an indentation significant enough to ensure the location of cable separation. The cable shearing mechanism is shown in figure 3 below. The final test

carried out determined the functioning of the circulation nozzles, such that the tool could be operated at the low circulation rates demanded by the specifications of the complete system. Successful completion of this test confirmed that the tool would cycle correctly at between 0.65 and 1.15 bbls/min fluid rate, within the design parameters.



Figure 3 – Cable Shearing Mechanism

Flow Control and Isolation – FCI™

In order to prevent damage to the pump / formation during pump shut-down, a flow control valve has been developed to provide control of the fluids during normal or emergency shut-down, or pump failure. The system provides an annular type seal, which has some inherent advantages over ball or flapper type seals, incorporated into the design. The internal of the flow control sub is shown in figure 4 below.



Figure 4 – Internal of the Flow Control & Isolation Device

The valve is run in the locked open position, allowing fluids to pass by as the completion is lowered into the well. Once the completion has been run, and the packer is set and the valve can be unlocked by pressurising through a hydraulic control line. The valve is opened again by pumping fluid, which causes the valve to lock at a pre-determined flow rate.

During normal operation, the valve remains in the locked open position. However, should motor failure occur, or there is a requirement to shutdown then the hydraulic control line can be pressurised to activate the valve. This will cause the valve to seal and prevent produced fluids from running back through the pump and into the formation potentially causing damage.

The advantage of the annular type seal relates to its ability to re-open should any sediment lie on top of the valve. Pressure below the seal of the valve during pump start up will lift the valve body enough to washout any overlying sediments. This can help prevent jamming of the valve during operation. Details of the flow control and isolation device specifications are shown in Table 2 below.

Specification	Value	Remarks
Max OD	5.75 in	
Length	24 in	
Max Tensile Load	150,000 lbs	Housing
Pressure to Unlock Valve	300 psi	Through control line
Min Rate to Lock Open	1.5 bbls/min	In vertical position
Max Design Flow Rate	15,000 bbls/day	
Max Isolation Pressure	5000 psi	

Table 2 – FCI™ Specifications

FCI™ - Testing

In order to ensure that correct functioning of the tool will occur during operation, a number of tests were carried out on the valve, as detailed below:

- Pressure integrity of housing
- Function test

The housing of the tool was tested to 5000 psi differential. The tool was then assembled and connected to a hand pump by means of a hydraulic line. This configuration was used to confirm the correct functioning of the tool. The valve was then locked open manually and pressure built up using the hand pump to unlock the valve. It was determined that a differential pressure of 300 psi was required to unlock the valve body and seat the sealing element.

A more rigorous approach was taken to ensuring that the valve would lock open during production operations, as failure to do so would result in reduced production performance. A test housing was machined to fit onto a flow loop, and fluid passed at different rates through the valve. The testing can be broken down into three distinct sections:

- Determination of flow required to lock open the valve
- Maximum back pressure on valve
- Maximum pressure drop at maximum design flow rate

These tests resulted in the modification of the tool to overcome some minor concerns.

The flow required to lock open the tool was initially higher than the required design specification, and unacceptable vibration was induced prior to locking being achieved. Although the valve body is centralised through a central stem, an additional centraliser was placed over the top of the valve to inhibit the vibration and wear on the seal seat during production. In addition, modification to the collet, which locks the valve open and the main spring that returns the valve body to the locked position helped to reduce the minimum flow rate required to lock the valve in the open position. The final design of the circulation and release sub will result in lockout being achieved at 1.5 bbls/min. The flow loop utilised during testing is shown in figure 5 below.



Figure 5 – Flow Loop Test Facility

In order to ensure no leakage occurs during closure of the valve, the tool was closed and turned around in the flow loop to simulate a pressure head. Pumping fluid through the flow loop resulted in a build up of pressure, and a differential of 6500 psi was achieved without leakage.

The final test was to confirm the pressure drop across the valve at optimum production rates. The valve is designed to operate at flow rates of up to 15,000 bbls/day. Fluid was passed through the tool at this rate, and the pressure drop across the valve was measured using calibrated pressure gauges. At the maximum design rate, a pressure drop of only 12 psi was measured, which was within design parameters

Conclusions

The problems with existing equipment for CT deployed safety systems have been reviewed. Although generally successful, inherent limitations in the systems utilised have caused problems.

Two systems have been developed to enhance the running, operation and retrieval of CT deployed ESP's. They allow: the circulation of fluids through the CT and into the casing annulus above the packer; fail safe release from the BHA which incorporates a cable shearing system to ensure a clean fishing neck by cutting the ESP cable and control of the produced fluids during pump-shut down / failure.

A flow control system has been developed which prevents produced fluids in the annulus damaging the pump during motor shutdown. The valve is locked open by flow and hydraulically unlocked by a dedicated control line. Design of the valve overcomes inherent problems with jamming due to sediments resting on top of the valve.

The systems overcome existing problems in current equipment, such as premature release during running of the ESP or circulation, cable extending from the fishneck and motor / formation damage during motor shutdown.

All components have undergone testing to ensure not only their integrity with the design specifications, but also to clearly evaluate and define their functioning criteria in accordance with design parameters.

Acknowledgements

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References

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