Abstract

Slickline often plays a vital role in offshore plug and abandonment (P&A) operations, either used in the phases of the operation that require slickline conveyance, or because logistical, footprint, operational, economical, environmental or regulatory parameters of a P&A operation necessitate full reliance on this small, light, cost-effective conveyance offering.

Today’s evolving regulatory requirements are leading to an increasing demand on the scheduling and design of P&A activities. For activities such as barrier placement, proof that the work is being carried out to the prescribed high quality is increasingly required both by the operators and the authorities. In addition, as the time, costs, and risks involved in carrying out an offshore P&A operation are considerable, possible savings and risk reduction are highly sought after by the customer.

P&A activities such as perforation, punching, cutting, device setting, and cement placement, previously done by electric line or with memory-based tools which required additional runs in the well and provided only post-job QC, can be carried out by digital slickline without any compromise to the efficiency and immediate certainty of the operation. Conducting these P&A activities with digital slickline enables efficiencies through equipment and logistics simplification, and people and equipment rationalization, as well as reductions in marine support requirements.

Time and cost savings and process risk reduction or elimination, important in their own right on a single well abandonment operation, are increasingly relevant when applied on a full field abandonment scope of work. In addition, the suitability of slickline conveyance in such environments as riserless intervention P&A operations (negating the need for grease injection pressure seal), is another important feature that is part-and-parcel of a digital slickline operation.

This paper will demonstrate, through actual field examples, the use of digital slickline’s inherent surface read out and command and control capabilities, the operational value of precision and clarity delivered in real time, and the specific P&A job recordability and capabilities that have been absent from slickline operations of past. Also highlighted are digital slickline’s facilitation of personnel and equipment reduction, and subsequent reduction in HSE exposure.

Introduction

Slickline conveyance and its related services have been used in the exploration and production (E&P) industry since its very early days, with much of the slickline equipment, processes, and capabilities remaining relatively unchanged throughout. Mechanical services have remained its mainstay with evolutionary enhancements occurring as a result of developments in metallurgical engineering applied to the line itself and the mechanical tools deployed, coupled with developments in the pressure control and winch technology used to safely deploy the tools and services in live wells. Oilfield application of battery powered electronics in downhole tools began in the late seventies, continually developing to include electronic-based devices such as gauges, firing heads, bottomhole fluid samplers, production logging and caliper tools as well as hydraulic tools. This brought about the first step out in slickline’s offering, expanding the slickline offering to both remedial services (pipe cutting, tubing punching, perforating) and measurement services (production, pipe and cement bond integrity logging). The demand
for slickline services has remained steady over the years due to its many inherent advantages, namely: minimal footprint; ease of logistics to, from, and on the wellsite; operational simplicity; and its overall cost-effectiveness. These advantages are becoming more essential for several reasons; firstly, because enhancement and optimization initiatives are increasingly required to help generate additional production from the now massive stock of depleting wells; secondly, because intervention requirements increase, from a well repair and maintenance perspective, as the industry works hard to ensure wells remain viable; and thirdly, for plug and abandonment treatment as the wells approach eventual end of economic life. As the demand for hydrocarbon energy continues to grow (taking exploration and development to new frontiers), the focus, attention, and budgets being assigned to field-wide maintenance, rejuvenation, and optimization initiatives of existing oilfields is on the increase. In many cases the investments being made in the brownfield environments are providing greater yields to the operators.

The demand for hydrocarbon and the resulting impact on oil price led to active developments in the subsea and deepwater arena in past years, resulting in an increased complexity of well placements and their associated completions. This has subsequently led to new and innovative well intervention capabilities being devised (and the associated equipment being engineered, developed, and deployed) as the need for intervention in these well types has come to fruition.

In parallel, past and existing requirements across the industry seek to minimize operational risk whilst delivering operational efficiency and excellence. Tools, equipment, processes, and people skills that address these growing requirements and can bring increased ease, efficiencies, control, and certainty to the operation whilst providing risk minimization (if not elimination), are continually in demand and are becoming the expected norm in what is now an extremely high-tech industry.

Cost management is also a key part of P&A operations, along with safe execution and quality outcomes. Enhancements to existing, and development of new purpose-built vessels and equipment, coupled with an intervention workforce that is growing in relevant and multiskilled capabilities, are in high demand— as is the expectation that the scope of work to be carried out is completed in the prescribed time and on (or below) the AFE budget set. Light weight, low footprint intervention systems can significantly lower cost if they can offer a broad range of services required and can be deployed on lower cost vessels.

Slickline services are not exempt from this, and most recently have seen a move to on-command services and job recording capability brought about through telemetry enablement of the slick wire, combined with purpose-built downhole tools and a computer command and acquisition system. With telemetry enabled slickline, its real-time data acquisition and control capabilities not only enhance and expand the remedial and measurement services on offer on slickline conveyance, but also the more routine mechanical services that make up the majority of slickline applications. This comes about through the intrinsic real-time measurements that are a core part of its offering, which includes toolstring shock, deviation, head tension, pressure/temperature, and GR/CCL positioning—all of which can be applied to all and any of the services run on slickline, enhancing them through a combination of real-time depth correlation accuracy, clarity and immediate certainty of action, and job data capture. Specific tools for on-command triggering of hydraulic or explosive devices also feature as part of the digital suite.

These core and tool-specific capabilities of digital slickline are leveraged in the P&A arena, where advanced levels of clarity, certainty, and recordability are fully expected from all services used. These factors are also particularly sought-after in high-cost, highly sensitive environments such as the Gulf of Mexico and for the more complex situations of subsea completions and deep water.

The digital slickline trigger device used for all explosives-related services such as device activation (e.g. plugs, cement bollers), pipe cutting and punching, and perforating, has been designed with a number of intrinsic safety features that were not previously available on slickline conveyance. The trigger is fully API RP 67 compliant and is designed to ensure that triggering of the explosives cannot occur without a positive command from the surface acquisition system. This signal would be sent by the operator only if and when absolutely ready to do so, following the correlation tie in and when all other precautionary measures required by the client and service company are in place. The correlation and eventual firing is managed with a single descent in the well. In addition, clear and concise shot detection is available on surface. This is visualized and recorded in real time from multiple sensors in the basic control cartridge (i.e., shock, head tension) as well as from additional sensors that may be included depending on the toolstring configuration deployed (i.e., pressure, temperature). Additional intrinsic safety features are inbuilt and activated in the event of a misfire, automatically or by operator command from surface.
Case examples

The following examples discussed in this paper are from two single-well subsea P&A operations and a subsea intervention operation recently carried out for two different customers in the Gulf of Mexico. In the P&A examples, where natural depletion and water encroachment had killed the well, there were no additional zones above to bring on line. Hence, it was concluded that the economic life of the well was spent, and as such the well was to be permanently abandoned. The overall well P&A program was typical: downhole sequence of cement plug placement in the tubing and across the perforations; the placement of bridge plugs and associated cement plugs in the tubing, casing and associated annuli at the required depth points within the well; the subsea tree removal and the cutting and recovery of some completion components (tubing hanger, SCSSV, tubing); the casing cutting and removal at the prescribed depth below the mudline; and the final site-clearance survey and completion certificate. The riserless intervention operations featured here required coordination of multiple service companies, each involved in a number of phases of the operation, working off a dynamically positioned multipurpose vessel with ROV capabilities for equipment placement and removal of the subsea components. In addition to the setting of the bridge plugs, there was also the need to punch the tubing or casing to enable the circulation necessary for the cement placement. As per good practice, gauge cutter drift runs were also done at various steps in the P&A sequence. High precision for the plug setting and perforation depths were needed in order to successfully place the cement barriers. However, limited deck space coupled with the desire to minimize the time taken and logistics needed for equipment change out for certain service providers led the customer to choose digital slickline above standard slickline, using this service to do slickline and equivalent e-line (electric line) tasks. Primarily, it was the real-time CCL correlation capability that digital slickline provides to its mechanical and remedial services that enabled uncompromised depth accuracy and efficiency for the bridge plug setting and tubing punching operations. It was the same for the tubing cutter placement in terms of the depth accuracy required and the certainty achieved, efficiently carried out in a single run with the real-time surface readout. In situ temperature and pressure readings were also taken during the drift runs at relevant depths and passed to the engineers designing the cement slurries and cement placement procedures, enabling the efficiency and quality of this component of the overall P&A operation.

The first operation was performed in 315 ft of water, utilizing a riser. Magna range bridge plug placement and cement dump bailing was carried out, with several runs done in order to place the desired cement column. A number of gauge ring drift runs were carried out primarily for tubing access confirmation, whilst simultaneously capturing the bottomhole temperature information needed for the design of the ensuing cement plugs. In addition, the requisite number of tubing punching and cutting operations were conducted. When initial plans to utilize the riser had to be changed for operational reasons, the client was able to quickly switch to a digital-slickline-deployed riserless operation for the final tubing puncher and tubing cutter runs.

The plot in Figure 1 is a screen capture of the information seen on surface in the slickline unit in real time during one of the bridge plug setting operations. As the plug setting device is triggered, the resulting toolstring shock and the change in the line tension displayed clearly indicate that the device has been set.

![Bridge Plug Plot vs Time](image-url)

**Fig 1:** Surface readout screen capture of the log versus time setting record for the bridge plug.
The plot in Figure 2 is a screen capture example from one of the many cement dump bailer runs carried out. Again, the toolstring shock measurement indicates the time of triggering, at which point the toolstring head tension immediately begins to drop as cement is dumped. The depth measurement captured clearly shows the procedure being followed by the slickline operator as he picks up the toolstring as the cement is being deposited. The final reduced head tension measurement indicates the successful completion of the cement dump bailing operation. All this information was available and displayed in real time in the slickline cab during the dump bailing operation.

Fig 2: Surface readout screen capture of the log versus time record for the cement dump bailer operation.

The plot in Figure 3 is a screen capture of one of the tubing puncher runs. For this run, the pressure/temperature sub was added to the toolstring, enabling the capture of a real-time pressure response to complement the shot detection and indicate successful penetration of the tubing. In this run, the toolstring shock response was immediately accompanied by a change in the head tension and borehole pressure sensed at the tool position. The head tension fluctuated as a result of the shock received from the charge detonation and the influx of annulus fluid, but also steadied out at a level slightly below the original tension, indicating toolstring weight loss associated with a spent puncher. Also shown is the pressure drop prior to detonation as the tubing pressure was bled off slightly.

Fig 3: Surface readout screen capture of the log versus time record for the tubing puncher run.

For all digital slickline runs, including those shown in the above figures, the accurate depth correlation required was provided during the same descent in the hole from the depth correlation cartridge in the toolstring. Being a P&A operation, the depth tie-in requirements were related to the completion architecture rather than the formation. Hence, only the CCL measurement was used for this purpose. Figures 4 and 5 below are screen captures from two correlation passes made in association with one of the tubing puncher runs. Such correlation data is provided in the run report and stands as a permanent record. Figure 4 shows
the correlation run done during placement of the puncher prior to shooting, carried out to ensure that the puncher was not being placed across a tubing joint which would have been detrimental to its penetration performance. The casing collars were seen in real time on surface, and the puncher then positioned accordingly. Figure 5 shows the logging pass that was done immediately following the successful tubing puncher run with the same toolstring. Confirmation of the tubing punch was seen from the CCL response, as well as the temperature spike seen on the log. Note also the reduced head tension seen on this logging pass, while pulling up at the same logging speed.

The second operation was performed in 550 ft of water, this time using an innovative riserless intervention system for pressure control. In this operation regular slickline was used pull the crown plugs and digital slickline was used for the majority of the P&A operations. Again, bottomhole temperature and pressure information was captured during gauge ring drift runs to assist in the cement slurry design. Obtaining this information was a critical requirement for the overall P&A operation. Also, slurry cure times can be optimized and save valuable wait on cement time. Capturing this data during the slickline operation negated the need to swap out seal flow tubes in the riserless intervention system for the e-line cable, saving much time and operational effort. This was in fact done using the digital slickline tool run in memory mode on standard slickline. Digital slickline was used to do a number of tubing puncher runs, as well as to trigger a 10-ft/6-shot-per-ft Big Hole puncher, used to penetrate both the tubing and the 9\(\frac{5}{8}\)-in casing.

In a separate recent subsea intervention operation, also in the Gulf of Mexico, digital slickline was used throughout the operation, including the removal and replacement of the upper and lower crown plugs in the subsea tree. Here, the water depth was almost 4,000 ft. The three plots below are screen captures of the information seen on surface in real time for the protector sleeve removal, the pulling, and the eventual setting of the lower crown plug in the subsea tree.

The plot in Figure 6 captures the pulling of the protector sleeve. Line weight drops when the toolstring tags the protector. Once engaged, as confirmed by the increase in line tension above the hanging weight of the toolstring when picked up, jarring is started. The shock created by the jar is seen, as is the increasing line tension applied on each jarring action. Finally, the protector comes free after four jars, as evidenced by the increase in hanging weight of the toolstring.
The plot in Figure 7 captures the pulling of the lower crown plug. For this operation a spring set power jar was used in order to manage the jarring in a slow and controlled manner, and was set to activate at 600 lbs. Also the digital slickline pressure sub was run to provide the pressure reading in the tree during the operation in real time. As can be seen, the initial line weight drops as the tool tags the crown plug. The subsequent pick up line tension then seen indicates that the pulling tool was successfully engaged, and jarring was started. After six jar attempts, as seen by the increase in line tension coupled with the shock measurement, the pressure steps up slightly, indicating the seal on the crown plug is broken as the well pressure equalizes across. One final jar and the plug comes free, as confirmed by the corresponding increase in hanging weight of the toolstring.

The plot in Figure 8 captures the setting of the lower crown plug. Here, the pressure sub was also run to provide the pressure visualization during the operation as pressure was used to set the plug in place. The tension clearly shows the hanging weight of the toolstring with crown plug prior to setting. Tension drops as the plug tags its seat within the tree, following which approximately 600 psi pressure is applied to hold the plug in place. Next in the sequence is the jarring down to shear some pins in the setting tool. Pressure is then increased further, creating approximately 5000 psi differential, and held for approximately 20 minutes. Once the pressure is bled off, the slickline is pulled up; creating an overpull of approximately 800 lbs to ensure the plug is set. Once confirmed, the final jarring is done to release the toolstring and setting tool, and the hanging weight it seen to be slightly less that at the start, due to the plug being left in place in the tree.
Fig 8: Surface readout screen capture of the log versus time record of the lower crown plug setting.

In addition to providing real time clarity on surface to the operator when carrying out subsea tree crown plug removal and placement operations with slickline, a process that can often be troublesome, such plots serve as an excellent and valuable reference for future operations.

Conclusion

The real well examples presented in this paper clearly demonstrate many of the capabilities of the digital slickline technology, specifically in its application to offshore P&A operations, highlighting the clarity and certainty that is provided to the slickline operator and customer representative through the plethora of downhole sensor measurements available on surface in real time.

The plots shown are representative real examples of the richness of the record keeping that is now available from a slickline conveyed operation. The jobs carried out benefited greatly from the flexibility, agility, and lightness inherently offered through operating using a slickline platform, but without any compromise needed to be made to the integrity of the measurement being acquired, or actions being carried out. Far from it, the examples shown demonstrate that this digital services platform provides levels of real-time shock detection and mechanical action status previously not available to intervention operations.

Through this telemetry enablement, slickline intervention has now become a data rich service providing invaluable information to aid safe and efficient job execution, as well as job records for archiving purposes and a knowledge reference for future operations.