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Improving Well Completion Operations on the First Five Zone Smart Completion on Multi-Lateral Well in Offshore Abu Dhabi

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Abstract

Reducing the number of wells along with the associated capital expenditure, while increasing the production capabilities, has been the target for most of the major oil operators operating in the mature field environment. Wells completed in multi-layered reservoirs with multi-lateral compartments using Extended Reach Drilling techniques has become common practice within offshore Abu Dhabi. Combining smart completion and multi-lateral technology has been proven to be one of the optimum solutions to achieve the well objectives. However, this increases the well complexity and subsequent risk. This paper outlines the recent success story of the first five-zone smart completion, performed in offshore Abu Dhabi. This paper will also highlight the challenges faced, and subsequent lessons learned throughout the installation and operational phases.

Achieving a successful well completion installation of a five-zone smart completion in a highly deviated well, with multiple hydraulic and Tubing Encapsulated Cable (TEC) lines in a multi-lateral well involves detailed planning in order to reduce the potential risks and challenges. In order to mitigate these completion challenges, detailed optimizations and improvements were harnessed to increase the success rate and minimize the risk. These optimizations included all aspects of completion design, equipment selection, equipment preparation and completion execution. Simplifying the well design, optimizing the job sequence, and well-planned completion installation procedures assisted with the efficiency of the operation and the overall outcome.

Well completion was safely executed ahead of the planned time and achieved the required well integrity requirements. Zonal isolation between flow control valves (FCV), completion tubing, and multiple gas lift mandrels (GLM) were all tested and confirmed as integral. All eight control lines in the completion were tested and confirmed as integral based on the function testing the flow control valves. The permanent down hole gauges (PDHG) were also fully tested before installation and readings taken pre/post installation to confirm their functionality.

The successful installation of this well has shown that an optimized well design along with preparation is the key factor to achieving success for a complex smart completion. A well-planned job execution similarly played a crucial factor in this installation. Utilizing proper running equipment, rig space management, and managing the multiple control lines, was also a key factor. This was further complemented by having well-trained service personnel, who were supported onsite during the execution phase which impacted the overall

success of the installation. There were, however, some aspects to the operations that require improvements, and this has been captured for any future operations.

This paper presents the practices used throughout the well design, and equipment preparation /installation that were adopted over the entire well completion to achieve the key objectives. It also highlights some challenges that were seen during the installation, and operations that allowed for the delivery of a quality completion. All the key learnings from this install, were captured as lessons learned and will be considered for improvements for any future well designs and operations for the future.

Introduction

The subject field of interest is a giant carbonate offshore field, located in the north of Abu Dhabi. This field is considered one of the largest offshore fields in the Arabian Gulf and has been in production for over 50 years. The giant carbonate reservoir is a heterogeneous reservoir with lateral discontinuity and geologically divided into three reservoirs with more than 40 sub layers based on the stratigraphy. This heterogenous complexity raises the risk of fluid movement that can lead to early gas and water breakthrough.

Initial development of this field consisted of vertical and deviated wells. Later horizontal and multi-lateral Extreme Reservoir Contact (ERC) wells were drilled and completed to maximize reservoir contact and improve well productivity. However, early breakthrough in some of the horizontal wells has resulted in high Gas Oil Ratio (GOR) above the internal guidelines. This high GOR has resulted in decisions to be taken to shut in some wells within the field.

In conventional offshore multi-lateral wells, with multiple drains, a decision to shut in a well due to early water or gas breakthrough detected at surface may potentially kill production from other productive drains, as possibly only 1 drain having early gas or water breakthrough issue. The requirement to have real time monitoring on each drain to detect early breakthrough, coupled with the ability to selectively Shut-In production from a drain or zone without intervention operations has become a necessity to be implemented on these types of wells.

Smart Completion Technology

Since the early development of this field, well completion design and requirements have changed and evolved over time. From the initial early-stage designs using conventional single or dual completions to a more complicated multi-lateral or smart completion as per recent operations. Conventional old wells were restricted to 1 or 2 zones, due to the inability to commingle, therefore additional wells were required to recover the remaining reserves from the reservoir. A conventional completion well would require completing the well as a dual completion due to limitations in commingling production.

Conventional well operations require slickline or wireline intervention to shift open or close the conventional sliding side door (SSD), along with pressure gradient surveys annually. Although slickline operations are considered straightforward and inexpensive, there still exists the potential for operational challenges in performing well intervention that may affect the total well operational cost. Besides the logistical limitations, weather, facility constraints, and having a highly deviated well, also adds to the complexity of performing well intervention operations.

Based on the challenges mentioned above, the key to optimizing the oil recovery comes down to the ability to effectively manage each zone with regards to production and/or injection. With the currently available technology for well completion, the objective can be achieved by using smart well technology, that has the ability to control production through different choke sizes. Furthermore, by utilizing downhole pressure and temperature gauges can also provide an additional benefit of providing real time monitoring of the system and assist on maximizing the oil recovery.

During the design stage, proposing a smart completion may be considered as involving high initial capital expenditure. But with the ability to allow multiple zones to produce, using commingled flow via flow control valves (FCV), this far outweighs the initial concerns of high costs and the additional benefit of reducing the number of wells required. An optimized design of a smart completion system will allow multiple zones with varying pressure values to be produced. This by itself has shown that a smart completion design could potentially reduce both capital and operational expenditure.

Another important benefit of a smart completion is the flexibility and ease of pressure and temperature data acquisition, achieved through permanent downhole gauges. The existence of real time data monitoring is crucial to ensure that any changes in the well during flowing or shut in, can be quickly captured and analyzed by the reservoir engineer. By having real time pressure data during well flowing conditions will allow continuous production evaluation, rather than having conventional flowing gradient survey's taken once a year. During well intervention or planned shutdowns for maintenance, pressure data can be utilized for pressure transient analysis. This allows for continuous reservoir properties and performance monitoring, to detect any potential issues in the well much earlier. The more acquisition data captured and analyzed, helps to reduce any uncertainty and assists the reservoir engineer to optimize the future development plan.

Well Design and Preparation

The objective of this well was to drill ERC multi-lateral well complete with 5 zones smart completion. The well was drilled as part of the technology advancement of multi-laterals (TAML) level 2 with open hole lateral drilled from a cemented liner. TAML level 2 is a classification of multi-lateral well, where the main bore is required to be cased and cemented, while the lateral is non cemented. Each lateral was equipped with limited entry liner (LEL) with a drop off liner system and swellable packers for compartmentalization to improve production on each lateral. A five-zone smart completion coupled with FCV and permanent downhole gauges were installed in each zones on this well, allowing for real time monitoring and intervention less production optimization.

Each horizontal drain was completed with blank pipe and limited entry liner. The limited entry liner technology had been utilized recently to optimize drain recovery. The deployment of these liners in the open hole was initiated through a drop off liner system complete with the running tool, where the system will be placed close to the open hole drain window. An open hole hydraulic packer and swell packers were also installed in the system for anchoring and isolation purposes and to optimize the production from each drain.

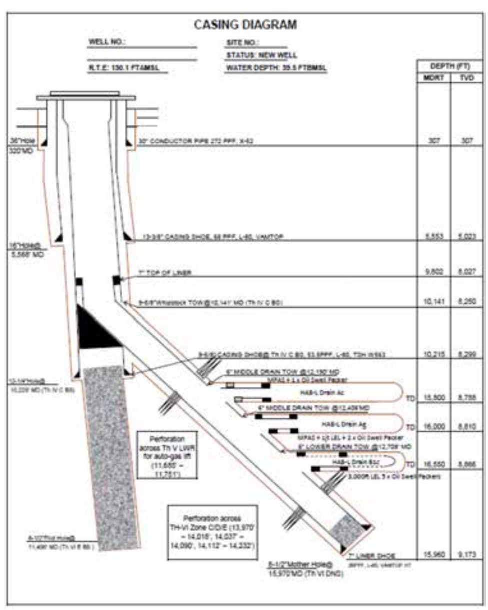

Figure 1—Casing Design

After installation of the smart completion with three to four zones on the same field, the requirement was to increase the number of zones, to become a five-zone smart completion which was the first to be implemented in Offshore Abu Dhabi. This requirement has increased the complexity and risk of the completion installation as more equipment and control lines are involved in the system. The five-zone smart completion consists of five flow control valves (FCV), five multi -port feed through production packers, Five dual permanent downhole gauges (tubing/annulus) monitoring both pressure and temperature from each compartment. There were eight control lines, consisting of six hydraulic lines (for n+1 hydraulic FCV system), one hydraulic line for tubing retrievable safety valve (TRSV) and one TEC line for permanent downhole gauge. The type of FCV installed in this well were hydraulically actuated flow control valves, with n+1 control lines. The n+1 hydraulic system consists of an open line for each FCV and one closing line.

Five-zone smart completion currently the maximum number of zones achievable to be deployed with n+1 hydraulic smart completion system for this type of well. This is due to the maximum available feed through ports on the multi-port feed through production packer that allows a five-zone system (n+1 hydraulic line and 1 TEC line). From a total of five-zones on this completion system, four-zones will be designated as production zones, while one-zone will be utilized for auto gas lift zone utilizing the flow control valve. This well was considered as a trial well, utilizing the hydraulic flow control valve system for gas lift in the field.

The completion design selected was a single smart completion with tapered tubing from 4-1/2-in to 3-1/2-in. The 3-1/2-in tubing section included the five-zone smart completion system and spaced out inside 7-in casing against production drains and perforations. The end of the 3-1/2-in tubing was equipped with wireline entry guide and barrier disc placed further up the completion as a packer setting device.

The barrier disc installation near the bottom of the completion was to eliminate the need for intervention during pressure testing of the tubing and facilitate the setting of completion packer after landing the tubing hanger. As this can be problematic with conventional slickline operations to set a bottom plug due to high well inclination. Also, a barrier disc at the bottom of the string was required for future intervention accessibility to the bottom zone as the barrier disc could be sheared open. Bottom most FCV was kept in the open position during Run In Hole (RIH) to enable string circulation as the barrier disc does not allow tubing to annulus communication.

The 4 1/2-in tubing section was spaced out inside 9-5/8-in casing up to surface. Conventional 4 1/2-in GLM were installed for future artificial lift application inside the 9 5/8-in casing. These five-oval type gas lift mandrels were installed with dummy valves and designed to accommodate a smart completion cables installation. A 4 1/2-in tubing retrievable safety valve was installed at a shallow depth with hydraulic control line connected to the surface.

Post completion phase, the well is planned to undergo several operational phases, such as well stimulation, shut-in, production flowing and gas lift injection to name a few. Extensive tubing stress evaluation and analysis were conducted pre-installation to simulate tubing conditions under multiple load conditions expected during the life of well. The final well design for the smart completion was validated to accommodate multiple load factors, and to ensure compatibility of the downhole equipment.

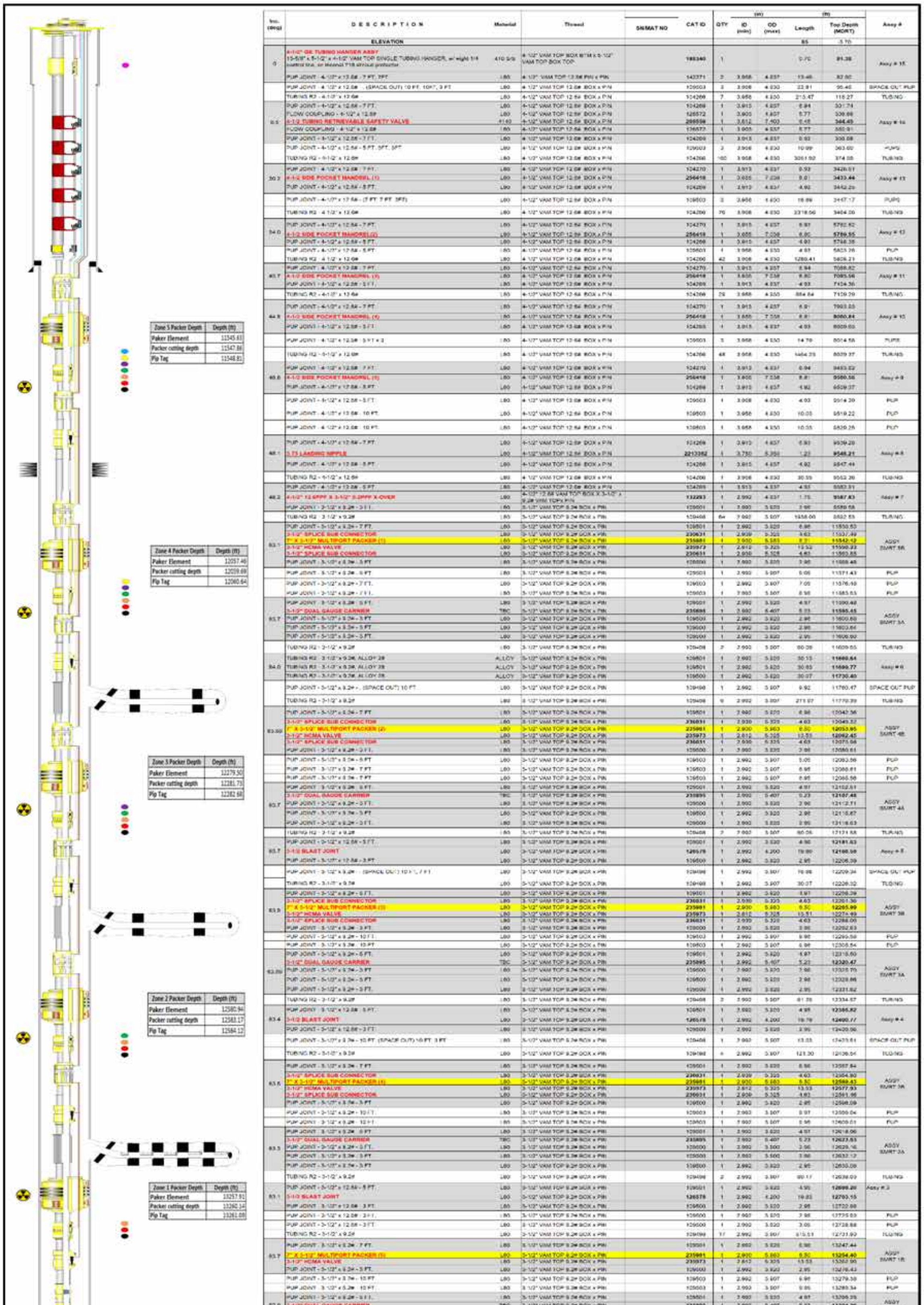

Figure 2—Completions Schematic

Rig Survey

Prior to performing the smart completion operation, a rig survey is crucial, to ensure whether rig is capable of handling smart completion operations. There are multiple running tools and control cabin associated with the smart completion operation. Not all rigs are capable of handling smart completion operations due to deck size limitation, cantilever design, crane position and rig floor size. The rig survey is highly recommended to be conducted a few months prior to rig spud-in to drill the well. Any potential issues and/or factors identified during rig survey may require changing rig allocation for performing the smart completion operations.

Some of the factors to be considered during rig visit include:

- Derrick Design - With three downhole lines to support; two triple flat packs, and one electric line, derrick beam has to have sufficient space for placing the spreader bar. Derrick beam must be certified to have safe workload (SWL) value higher than the combined value of break force of all flatpacks and control lines. To reduce the congestion in the beam, a spreader bar is utilized to hang three sheave wheels that can accommodate the two triple flat packs and TEC. Average cable break force value for one single quad flat pack was 14,000 lb/ft. and for one TEC cable will be 4,000 lb/ft.
- Cantilever deck layout - Smart completion running tools consisted of spoolers and cabin. Cabin and multiple flatpack spoolers positioning on the deck had to be planned to ensure the positioning did not cause any obstruction of the rig crane movement during the pipe handling and lifting of smart completion assemblies. The electrical power source and air supply to operate the running tools also needed to be considered to ensure the tools could be operated. The cabin runs on a specific voltage rating, and this needed to be confirmed with the rig so they could provide the desired voltage. Any incompatibility issues on electrical voltage or air supply could lead to potential equipment damage and Health, Safety and Environment (HSE) risks during the installation stage.
- Rig floor layout – Rig floor layout needed to be planned in such a way that personnel movement on and around the rig floor was not hindered, and equipment positioning allowed seamless rig floor operations. The drillers' view should not be obstructed during any operations. Hence it is important that positioning of the power tongs, control lines (location of the sheaves dictates the direction of the control lines) and personnel movement is to be mapped to ensure good visibility of each other and a safe working environment for all personnel involved on the rig floor. Planning rig floor lay out for smart completion operation was required to ensure smooth rig floor operation and prevent any HSE risk.

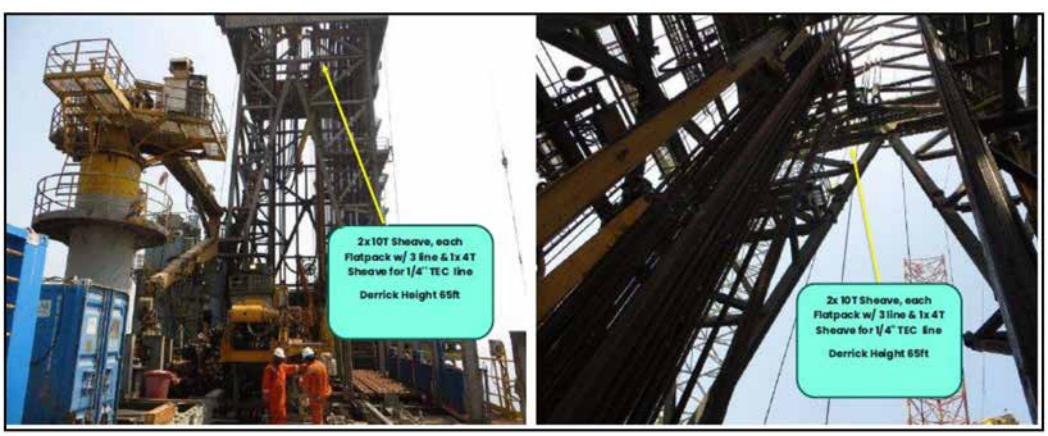

Figure 3—Rig Derick

Figure 4—Rig Deck Lay Out

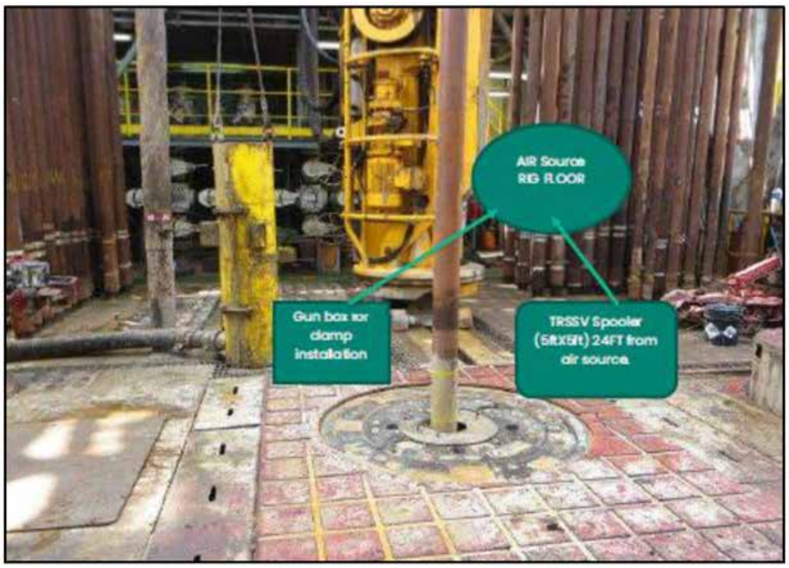

Figure 5—Rig Deck Lay Out

Sub Assembly Preparation

All completions sub-assemblies were prepared at the workshop, according to planned schematic. All assemblies were made-up, inspected, and tested. A total of twenty-seven sub-assemblies were prepared for this operation: Smart completion assemblies, conventional gas lift mandrels (GLM) assemblies and back up assemblies. All these assemblies were tested to 4,500 psi as per the well requirement.

To ensure operational efficiency, the smart completion tools make-up design was planned in such manner that would enable seamless operation during installation stage. As shown on Figure 6, multi-port feed through packer, flow control valve and splice subs were assembled to be made as single assembly, and the gauge carrier was made as another assembly for the respective zones. Hydraulic control lines were pre routed through the multi-port packer and terminated. This way the only operations needed on the rig floor during the installation stage was to connect the hydraulic lines on bottom and top splice subs. The TEC was ran as a single conductor line, from top to bottom of the string, hence the feed throughs for this line were completed on the rig floor. Each assembly was marked with specific labelling to ensure assemblies were easily identified and ran in order. Radioactive pip tags were installed on each multi-port packer, to enable identification of the cutting point reference for the multi-port feed through packer during future workover operations, if required.

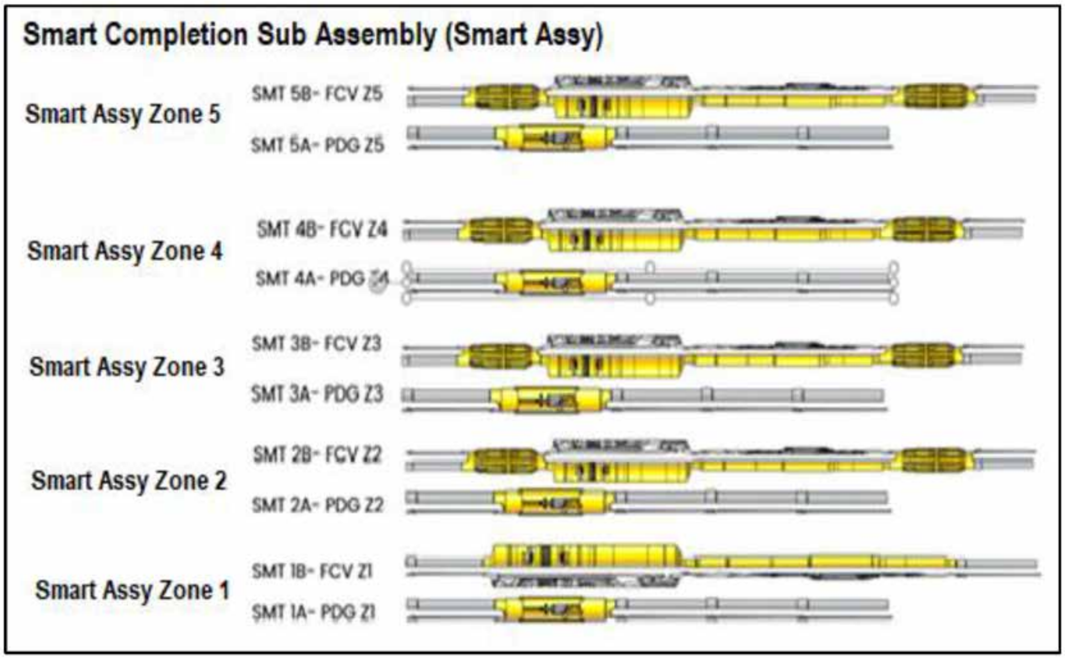

Figure 6—Smart Completions Sub-Assemblies

During workshop preparation, all the FCV assembly were function tested with the hydraulic line connected to the port. All the pressure values and volumes of fluid observed during workshop FCV cycle tests (fluids pumped and returned fluid volumes) were recorded as a benchmark for the rig installation. Any deviations from this workshop value might indicate contamination or leakage on the hydraulic line, which would affect integrity of the FCV system.

Figure 7—Flow Control Valve Workshop Test

Commodity No.				FCV			Sleeve Serial No.	Primary							Well No or Location
Size:				After Completion Shift Log			Cycle No.		x / Cycles						
Pos. No	**Date**	**Starting Sleeve Position**	**Start Time**	**Apply Press to Line**	**Stop Pump**	**Shift Pressure**	**Max Pressure (psi)**	**Total Pump Time**	**Final Sleeve Position**	**Returns Start**	**Stop Returns Time**	**Actual Returns (mL)**	**Expected Volume**	**Bleed off Volume**	**Notes**
1	dd/mm/yy	100% Closed	hh/mm	Open - TBD					Close	min	min	mL	mL	mL	
2	dd/mm/yy	3.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
3	dd/mm/yy	Diffused	hh/mm	Open - TBD					%	min	min	mL	mL	mL	
4	dd/mm/yy	5.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
5	dd/mm/yy	Diffused	hh/mm	Open - TBD					%	min	min	mL	mL	mL	
6	dd/mm/yy	7.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
7	dd/mm/yy	Diffused	hh/mm	Open - TBD					%	min	min	mL	mL	mL	
8	dd/mm/yy	10.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
9	dd/mm/yy	Diffused	hh/mm	Open - TBD					%	min	min	mL	mL	mL	
10	dd/mm/yy	15.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
11	dd/mm/yy	Diffused	hh/mm	Open - TBD					%	min	min	mL	mL	mL	
12	dd/mm/yy	40.00%	hh/mm	Closed - TBD					-	min	min	mL	mL	mL	
13	dd/mm/yy	Diffused	hh/mm	Open - TBD					Full Open	min	min	mL	mL	mL	
14	dd/mm/yy	Full Open	hh/mm	Closed - TBD					%	min	min	mL	mL	mL	
Working Pressure:				psi											
Control Chamber Pressure (max)				psi											

Figure 8—Flow Control Valve Pump Chart

4-1/2-in gas lift mandrel sub assembly (five each) were prepared. These mandrels were made up and tested at the workshop with dummy valves installed. Additional precautions taken during dummy valve installation on GLM, where camera was deployed to observe latching position of the valve against GLM pocket. These gas lift mandrels was customized to support smart completion operations. Control line bypass rails on both sides of the mandrel were installed. These rails are capable to secure two triple flatpack cables and one TEC with lock pin to secure the lines.

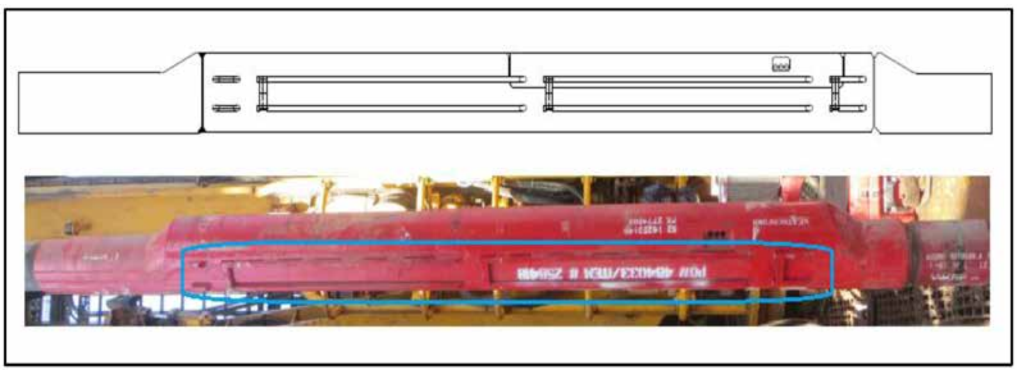

Figure 9—Gas Lift mandrel for Smart Completions

Tubing Hanger System Integration Test

Simulation of smart completion tubing hanger operations were performed at the workshop to replicate actual operations on the rig. This was required as tubing hanger landing operations are one of the crucial steps of the smart completion operation. During the workshop tests, all control lines to be terminated in the completion were simulated on tubing hanger body as per planned installation. Each feed through port on tubing hanger was marked and dedicated for specific control line, for safe and efficient installations purposes. Control line wrapping arrangement was also simulated to ensure no lines are damaged during tubing hanger landing operations. Bending caps were used on each control line to prevent any over bend stress which could cause kinks; potentially compromising the line integrity. Bending caps were used on each control line to prevent damaging control line during wrapping operation. X-mas tree landing were simulated with penetration port for all hydraulic and electric lines was also decided and marked on the Adapter Port below the X-mas tree.

Figure 10—Tubing Hanger System Integration Test

Torque and Drag Design

The horizontal inclination of the well was more than 80°. Torque and drag analysis are important to understand to severity of the torque or drag issues the completion string will be exposed to. In the design stage, worst case scenario was considered by utilizing maximum friction factor. High dog-leg factors were also analyzed during the design stage to prevent accessibility issues.

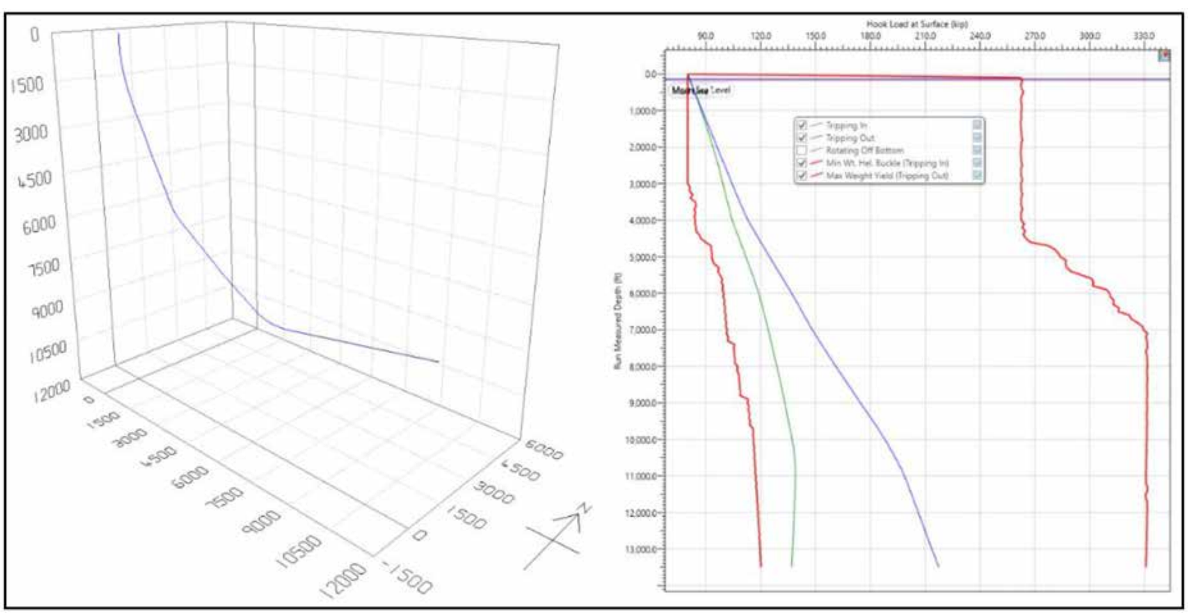

Figure 11—Run In Hole Torque and Drag Analysis

String rotation and applied slack off weight will be the limiting factor to be considered during the Torque and drag analysis. Completion string should not be rotated at any point; due to the fact that multiple control lines installed on the downhole tools could get twisted and lose integrity. As for the slack off weight, although there is no sting in (to lower completion) operation, this is factored in the analysis to understand what the maximum slack off weight that could be applied to the string during the operation. This also could assist in applying slack off weight in order to push the string through in case any drag is observed. Pull out of the hole (POOH) scenario were also considered as part of the well design, in case the completion string needed to be retrieved due to a well obstruction or well control issues.

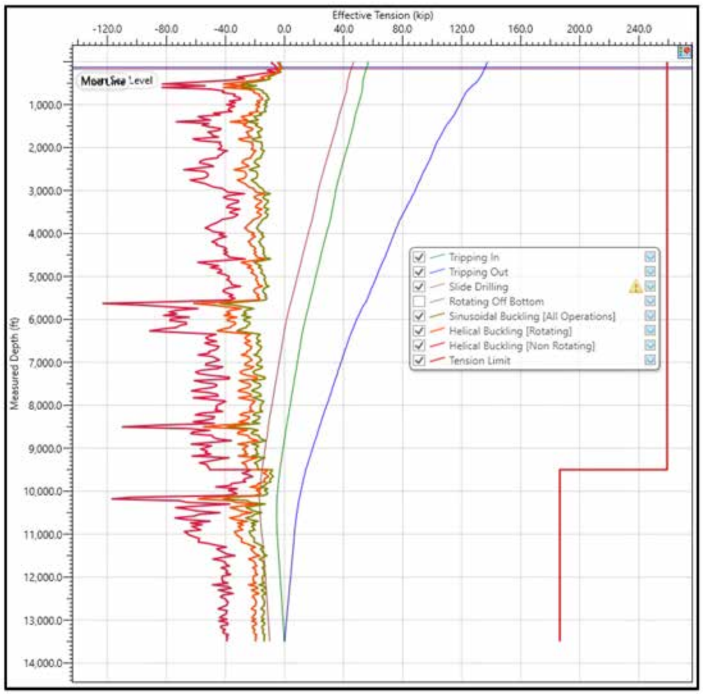

Figure 12—Completions Tubing Stress Analysis

Well Completions Operations

Upon drilling completion of the last drain, Upper completion operation to commence. Sequence of well completion operations are:

1. Wellbore clean-out (Pre-Perforation).
2. Perforation.
3. Wellbore clean-out (Post Perforation).
4. BOP Jetting.
5. Rig set-up for RIH smart completion.
6. RIH smart completion.
7. Land completion and terminate all control lines.
8. Set and test completion.
9. Injectivity and zonal isolation test.
10. Nipple down blow-out preventer, nipple up X-mas tree.
11. Diesel displacement.

Wellbore Clean Out

Well cleanliness is one of the most critical criteria prior to running the smart completion. Excessive metal junk inside casing could potentially cause an issue with the smart completion system. Several flow control valve failures were due to debris that was reported, causing "non-operable" valves and leading to a decision to POOH completion. Tubing accessibility also will be confirmed through the wellbore clean- out operations. Torque and drag simulation were performed during design stage will be verified through these operations. Any obstructions observed during this trip will need to be cleaned out. Clean completion brine will be circulated, displacing previous perforation brine.

Clean-out BHA utilized for this well included scrapper, string mill, high strength magnet, debris recovery tool and circulating tool. One of the common issues during wellbore clean out in ERC or high inclination well is achieving effective debris circulation, conventional wellbore clean out operations with single circulation port at the bottom of BHA may not be effective to transport all debris back to surface. Having additional circulation ports in the middle of well will help to increase the flow rate inside 9 5/8-in casing and improve debris circulation back to surface.

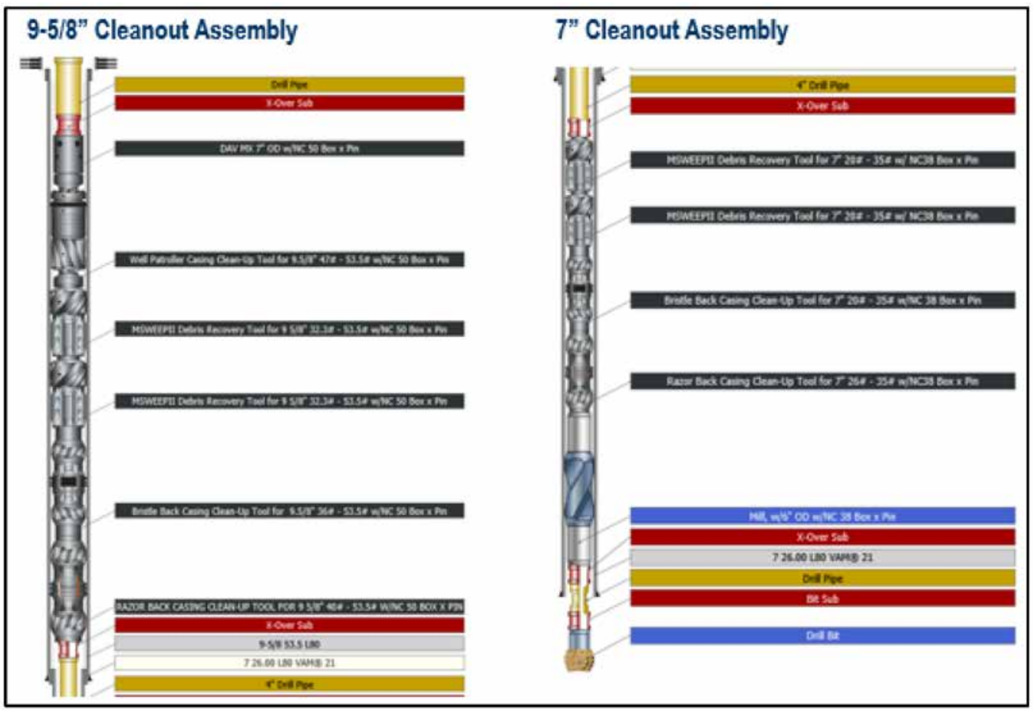

Figure 13—Well Bore Clean Out BHA

Well clean out acceptable criteria was set up to ensure smart completion ready to be deployed. Clean out criteria, includes total soluble solid (less than 0.02 %), nephelometric turbidity units (NTU) (maximum 40 %) and quantity of debris recovered on magnets and junk catcher less than 75%. Additional trips will be mandatory incase clean out criteria is not achieved after the first run.

Rig Set Up

Equipment rig up was based on previous agreed rig lay out, as shown on Figure 14. Some items needed to be backloaded or rearranged to create space and ensure no obstructions on the planned working route. Different types of sheave wheels and spoolers (for TEC and Flatpack) were rigged up, secured and function tested with loads. Rig floor arrangement to follow planned equipment lay out. Tubular running equipment set up at designated area. Special tubing slips for smart completion operations installed to support multiple flatpack cable and TEC installation.

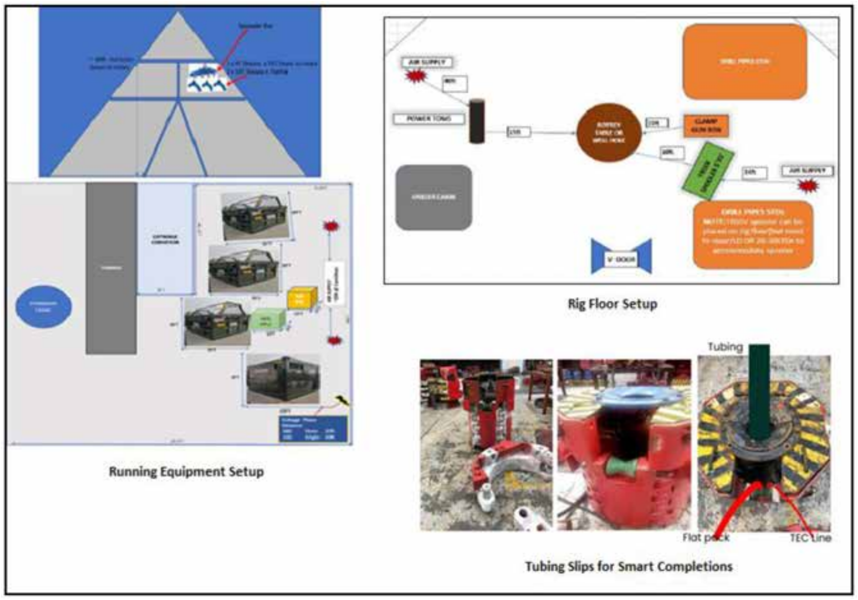

Figure 14—Rig Setup for Smart Completions

Run In Hole Completions

Operations commenced by confirming readiness of all pre-assembled smart completion assemblies and surface running equipment. Well conditions also needed to be verified to ensure stable condition, any well control condition must be resolved prior to commencing completion operations. Operation continued by picking up each assembly as per approved completion tally.

Control line management is a critical part of the operations. While RIH with eight control lines, each control lines were color coded, in which each color code represents the open and close lines of the FCVs. These color codes were followed throughout the completion installation until the wellhead termination points.

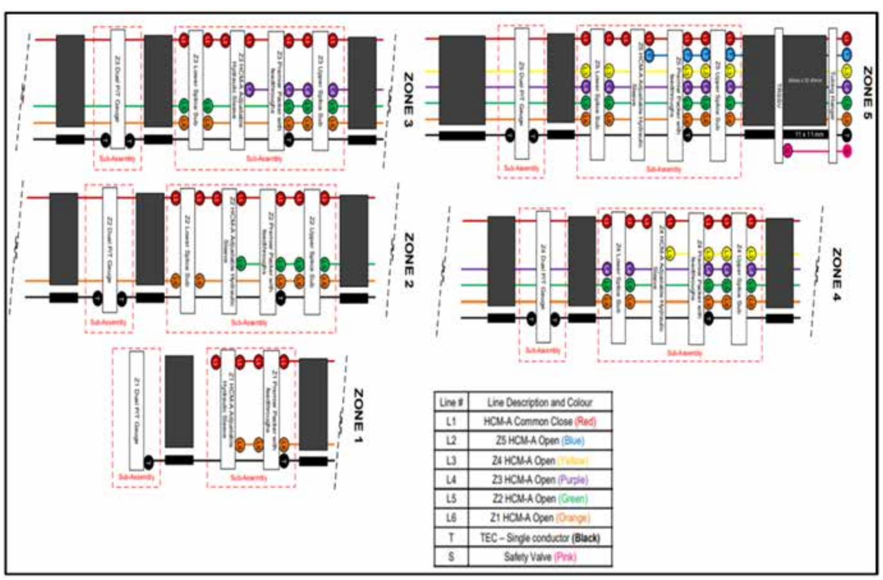

Figure 15—Hydraulic Control Line Management

To ensure control line integrity, special care was taken on handling these lines while running in hole and making up connections. Due to the criticality of the line management, additional time was allocated to accommodate slower RIH completion, splicing control lines on each zone and pressure testing of lines after control lines were made up to splice sub connections. On each tubing joint connections cross coupling protectors will be made up to secure multiple control lines on the tubing. Consistency on arranging control line to be secured on assigned cable protector slot on each tubing joint connection helps on maintaining control line integrity.

Smart completion assemblies for each zone consisted of two downhole tools which were the FCV assembly and gauge carrier assembly. Hydraulic lines for each zone were terminated at the splice subs as the connections to the FCVs were pre-made during the workshop preparation. Hydraulic lines from bottom zone were terminated on the splice sub and then connected with the line on the feed through on multi-port packer from above. During the TEC termination onto the permanent downhole gauge, the power to TEC will be switched off to prevent any short circuits. Power will be turned back on once the termination is completed to ensure good communication between the surface systems and the permanent downhole gauge. Each zone FCVs were function tested upon termination to ensure full valve functioning and choke shifting are as per tool functionality.

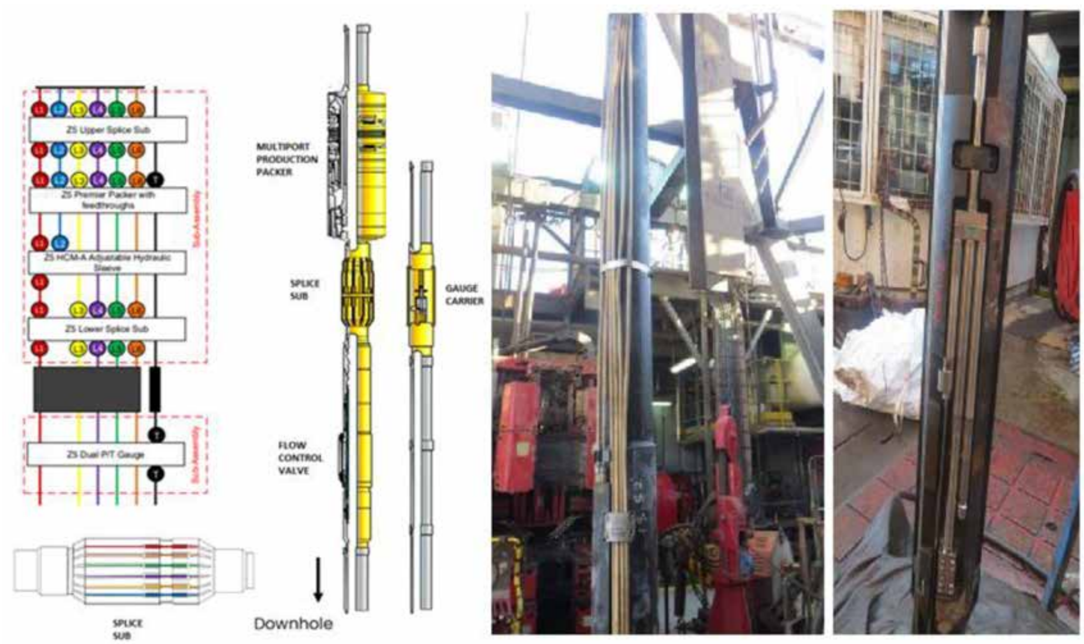

Figure 16—Smart Completions Zonal Configuration

During RIH the smart completion with closed end, will require bottom most zone to be kept open, to allow for circulation during the operations, while other FCV's remain in closed position. Pressure will be maintained on each hydraulic line during RIH completion assemblies after connecting and tested to ensure FCV valve position is not shifted to any other position during RIH.

Table 1—Zones FCV Status during RIH

VALVE POSITION TABLE					
HCMA	**Zone 5**	**Zone 4**	**Zone 3**	**Zone 2**	**Zone 1**
Choke Position	Fully Close (Position 1, Finql Sleeve Position)	Fully Close (Position 1, Final Sleeve Position)	Fully close (Position 1, Final Sleeve Position)	Fully Close (Position 1, Final Sleeve Position)	100%(Indexing Position 14)

During RIH of completion, it is critical to maintain flat pack and TEC cable tension, to prevent damage due to slacking cables. Permanent downhole gauge data were continuously monitored. Dedicated personnel were always beside the spooler unit to ensure control lines were always under tension and downhole data were always monitored. The hydraulic line integrity were monitored by locking in 1,000 psi throughout the completion running in hole. Any loss of pressure will indicate loss of hydraulic line integrity.

Communication protocol between driller on rig floor and spooler operator must be available, to allow effective co-ordination. Any string movement will need to be communicated between the driller and the spooler operator. In case any restriction is observed during RIH, only tubing axial movement and circulation is allowed, tubing rotation is not permitted.

Total five gas lift mandrels were made up on the completion with dummy valves pre-installed during workshop preparation. Hydraulic control lines from FCV have to be secured on the gas lift mandrel rails, and the securing side has to be consistent on one side for all the gas lift mandrel assemblies.

TRSV assembly was made up and function tested with required maximum opening pressure after hydraulic control line connected. Both flatpack and TEC lines secured on TRSV with special protector. Crucial factors to be considered with TRSV is its OD. The OD of the TRSV has larger OD versus the ID of the slips. Hence, it was required to remove the automated slips to ensure smooth passing of the tool. Automated slips were installed back again once the tool has passed through.

Tubing hanger assembly was made up after tubing space-out finalized. All eight control lines were fed through the tubing hanger. Since the operations was conducted at heights, scaffolding was required to support the feed through operation. The operation was repeated as per the outcome of tubing hanger system integrity test conducted during the well planning. Integrity of the hydraulic lines and TEC were monitored by conducting temporary splices to the control lines and TEC from surface. This way all activities taking place during landing of the tubing hanger until setting the multi-port feed through packer can be monitored.

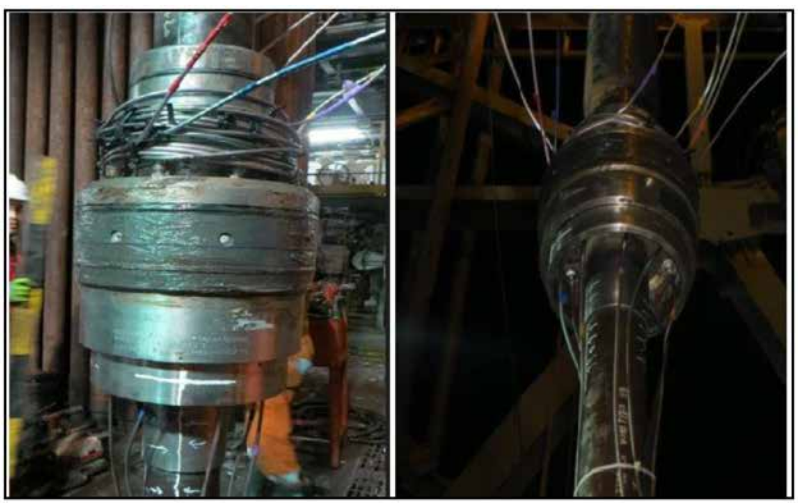

Figure 17—Tubing Hanger Termination

Upon landing of the tubing hanger, tubing test, packer setting, and inflow testing operations were conducted. Bottom most FCV will be cycled and shifted to close position to close any communication between annulus and tubing. Once the packer has been set against the barrier disc. Slickline operation was performed to set plug below the bottom most GLM. This step was taken to ensure gas lift valve doesn't unlatch and dropped in hole, during the annulus test.

To confirm all the multi-port feed through packers were set, and isolating each zone, each zone FCVs were shifted fully open and closed after injection operations in each zone. The downhole pressure was monitored in respective zone to confirm injection pressure doesn't leak into the zone above and below. The downhole gauge on zones above and below of the respective injected zone will show significant changes if the packer integrity is compromised.

X-mas tree successfully landed as per the plan. All hydraulic lines and TEC terminated on designated port on the tree body. Control line termination ports were tested to maximum X-mas tree rating. Each control line was then reconnected to surface unit to check integrity. Post completion operations, the string was bullheaded with diesel after opening bottom most FCV. During the diesel displacement operations, downhole pressure and temperature data from permanent downhole gauges were confirmed with actual expected well pressure. All FCVs indicated good volume returns during valve cycles indicating FCVs were functional. The well was then secured and handed over to production.

Figure 18—XMas Tree Termination

Overview and Lesson Learned

Five-zone smart completion was successfully installed as per planned well design. Post installation results indicate that all required barrier and zonal isolation was achieved, as per the well integrity requirement. All the FCV's and permanent downhole gauges were functioning normally, post completion during final bottom FCV cycle and TEC line was also giving expected pressure and temperature data. This indicated that smart completion control system are integral, with all zones functioning as per expected.

Operational wise, the duration required for commencing well completion operations for this well was under the planned AFE by forty-eight hours. There was no "non-productive time" capture throughout the completion installation. This was due to some optimization implemented from previous well best practices. Downsides recorded throughout completion operations where additional post perforation wellbore clean out trip required to be performed prior to running the smart completion, due to well cleanliness criteria that was not achieved after 200 ft of perforation.

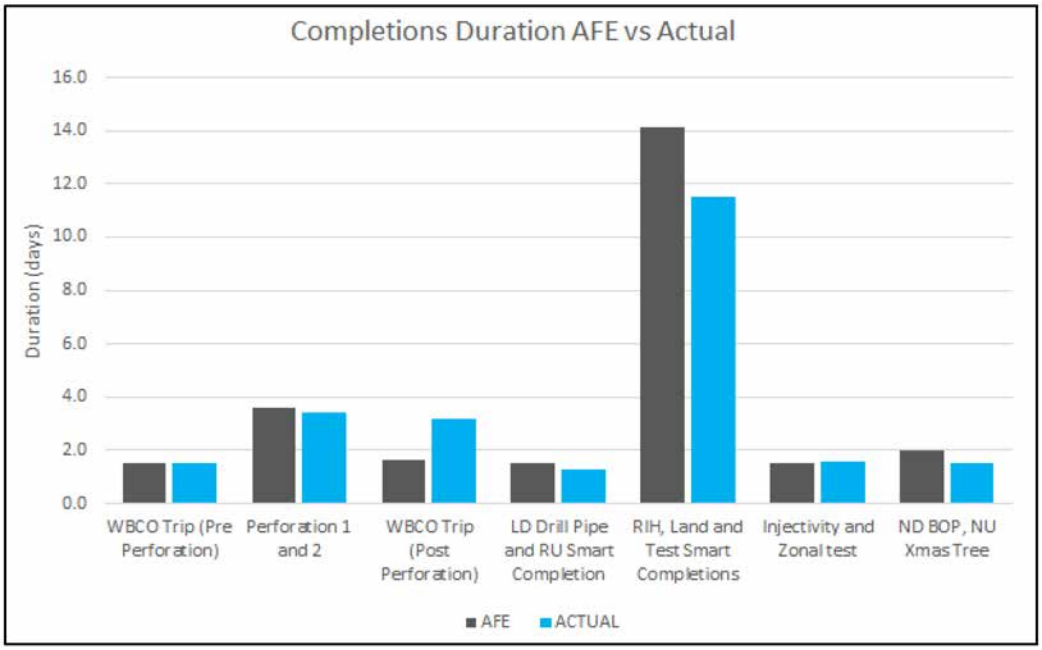

Figure 19—Completions Duration AFE vs Actual

In general time improvement was seen on smart completion assembly make up and test, compared to previous similar operation. As shown on Table 2, improvement was seen on smart completion zonal make up time, from the first to the last well. Utilization of experienced personnel and same crew involved throughout the smart completion well shows improved efficiency with the operation. Several discussions were conducted during planning, pre job and in the middle of operations ensuring all involved parties on the rig or as support onshore where aware and know their assigned tasks. Risk assessment was broken down into detail on every operation and re-emphasized on every pre-job meeting. Optimization on equipment sub-assemblies simplified the operations and improved the rig time.

Table 2—Duration Comparation with other Smart Completions Well

	MU and Test Zone 1 (hour)	**MU and Test Zone 2 (hour)**	**MU and Test Zone 3 (hour)**	**MU and Test Zone 4 (hour)**	**MU and Test Zone 5 (hour)**
Well-1 (3-Zones Smart Completions)	18	21	25		
Well-2 (4-Zones Smart Completions)	26.5	20	24.5	24.5	
Well-3 (4-Zones Smart Completions)	20.5	25	22.5	25	
Well-4 (5-Zones Smart Completions)	***19.5***	***19.5***	***20***	***24***	***21***

From these operations several learning experiences from design, execution and post operations stages were captured. These learning points will be valuable for improvement purposes and considerations for future well operations. The lessons learned includes:

1. Experienced personnel are regarded as the key for successful operations. Utilizing same personnel for the hole campaign will reduce risk of human error.

2. Detail well planning and design is very important on executing horizontal smart completion. Torque and drag for simulation, tubing design, job sequence planning, control line management, etc., will have to be properly done prior to execution to mitigate any failure risk.
3. Designing horizontal drain on multi-lateral smart completion well requires detail planning to confirm the compatibility and optimization of smart completion. Spacing out between drains or perforations will impact on assembly preparation and execution.
4. Optimizing wellbore clean out operations are required to ensure clean fluid prior to running completion. The setting position and required number of additional magnets and circulation tool will need to be optimized to ensure well cleanliness prior to Run in Hole smart completion.
5. Extensive compatibility study of all service equipment must be done during well planning. Minor issues were encountered with the tubing slips ID clearance, further alternative equipment needs to be investigated.
6. Some equipment designs will need to be revisited to avoid complications during execution of the smart completion. Modified gas lift mandrel rails design should be improved to simplify the operations.
7. Improvement on duration spent on each zone make up during completion operations observed from time to time showed that there are room for improvement in relation to rig time.
8. Any zonal isolation and injectivity test shall be performed as post completion operations and to be optimized. The significant rig time spent to full cycle each FCV on zonal isolation test should be optimized or minimized.
9. Equipment sub assembly preparation is critical step that reflects successful installation of smart completion. The existing smart completion assemblies has helped in simplifying operations, by having pre-made hydraulic line feed through. Further study needs to be considered on having TEC line pre-made in the workshop, hence no packer feed through operations during zone assembly make up.
10. Rig layout planning for smart completion operations was very important on ensuring rig readiness and compatibility. Optimized rig lay out design for smart completion operations will help to minimize HSE risk and optimize the operations performance.
11. Having countless meeting, namely risk assessment meetings, complete well on paper meeting, pre-job meeting, even only a short 5-minute meeting, attended by involved personnel will always have positive impact on the operations.

Conclusion

Smart completion operations are typically associated with high complexity, high cost and high risk. The number of control lines involved, amount of time required to make up and test the assemblies and specific rig setup required have caused this type of well to become non favorable for some oil and gas operators. Several failure cases globally related to smart completion operations also contributes to these misconceptions. The successful deployment of the first five-zone smart completion on multi-lateral well in offshore Abu Dhabi shows that with optimized planning and execution, high complexity level of well operations can be managed and controlled. The ability to merge and commingle several drains production into one single wellbore has contributed to a significant cost saving from drilling one or two wells to achieve identical drainage area while optimizing utilization of wellhead tower slots. Having real time surveillance and the ability to control production without intervention has cut operational cost and reduced the risk.

Furthermore, there is still room for improvements to be made to increase the performance and simplify the operations. Further improvement on completion sub-assembly and minimizing zone cycling operations could have a significant impact on reducing rig time. Reviewing other recent smart completion technology (such as electric type) could potentially add more benefit in simplifying some of the complication encountered during well planning and execution.

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Nomenclature

ERC	Extreme Reservoir Contact
TEC	Tubing Encapsulated Cable
FCV	Flow Control Valve
HSE	Health, Safety and Environment
X-mas	Tree Christmas Tree
TRSV	Tubing Retrievable Safety Valve

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