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Successful Coiled Tubing Fishing Operation Uses Hybrid Cable Connected Tools to Evaluate/Validate Downhole Data in Real-Time: A Case Study in the Eastern Foothills of Colombia

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Abstract

New downhole coiled tubing (CT) technology was used to facilitate the success of a challenging fishing intervention and to verify the reliability and accuracy of CT operations/simulation software. The technology supplies the newly designed bottomhole assembly (BHA) with continuous power from, and fiber-optic communications with, surface equipment, enabling accurate, real-time monitoring of measurements of bottomhole conditions.

Uncertainty exists in operations using CT regarding whether the planned axial force is transmitted from the surface through the pipe to the BHA and whether the BHA is functioning according to plan. During fishing operations, unless the BHA applies a minimum amount of force (compression and/or tension) to the fishing neck, the particular intervention run will be unsuccessful. The BHA then needs to be returned to the surface without recovering the fish.

This paper presents a case study of a well located in the foothills of Colombia in which a perforating gun became stuck following an operational issue. This situation resulted in an oil production reduction of 30%. Several fishing attempts were performed using conventional CT to recover the stuck perforating gun and to restore production to its previous level.

The initial lack of real-time BHA data and the inherent nature of CT elongation and buckling led the operator to believe that the fish was being recovered to the surface; several runs were performed with unsuccessful results. A CT string, equipped with fiber-optic communications and a continuous power supply to the BHA, confirmed that the perceived movement of the fish was not real and that the BHA selected was not generating nor transferring the expected force to the fish. The force transmitted by the pipe and the upward/downward impact force generated by the jar were measured in real time and determined to be consistent with simulated forces; the BHA configuration used for the operation was then redesigned. The new design led to the successful recovery of the fish and the return of well production to its initial level.

The real-time data measured during the fishing operation favorably compared to the simulated forces predicted during job design and execution. The accuracy and reliability demonstrated by the CT simulation

software in use enabled the operator to gain confidence in all simulations performed with the software for future CT operations.

This case study is the first known instance in which CT was used in conjunction with downhole tools that were supplied with continuous power to sensors to enable measurement of parameters, including force, pressure, temperature, torque, inclination, phasing, acceleration, gamma ray, and casing collar locator (CCL). This technology was supported by reliable software capable of simulating downhole conditions with precision and accuracy.

Introduction

Software development is the process of conceiving, specifying, designing, programming, documenting, testing, and bug fixing while creating and maintaining applications, frameworks, or other software components. As with any problem-solving activity, determination of the validity of the solution is part of the process. This paper discusses evaluation and analysis of data acquired from real-time hybrid CT services that can be used to validate CT software solutions for more precise and reliable execution and maximized well performance.

The real-time hybrid CT service is a step change in the industry, integrating fiber-optic and electric communication and power. The system is fully compatible with wireline and mechanical tools to offer unlimited flexibility in diagnostics, design, and delivery of the operations. Downhole measurements taken at the BHA include pressure (inside and outside the CT), temperature (T), inclination, tool face, gamma ray, load weight-on-bit (WOB), tension and compression, torque, triaxial vibration, and CCL. The service monitoring capabilities include distributed fiber sensing technologies, such as distributed temperature sensing (DTS) and distributed acoustic sensing (DAS).

The real-time service includes well intervention software that keeps simulated thresholds updated and on-track in the CT cabin. Every model uses computational simulations and empirical data to identify operational limits and opportunities. The user interface is composed of detailed, context-related help files, along with a warning and messaging system based on actual physical conditions and lessons learned. It provides immediate guidance to CT providers and helps them operate to the limits of their equipment safely and efficiently.

The real-time data measured during the fishing operation favorably compared to the simulated forces predicted during operation design and execution.

Background

In the eastern foothills of Colombia is located a well with 36.95° of deviation and 7.67°/100 ft of dog leg severity (Vera et al. 2018a), with the configuration shown in Fig. 1. The production of the well was 4184 BOPD, 51.1 MMscf/D, and 1.45% basic sediment and water (BSW).

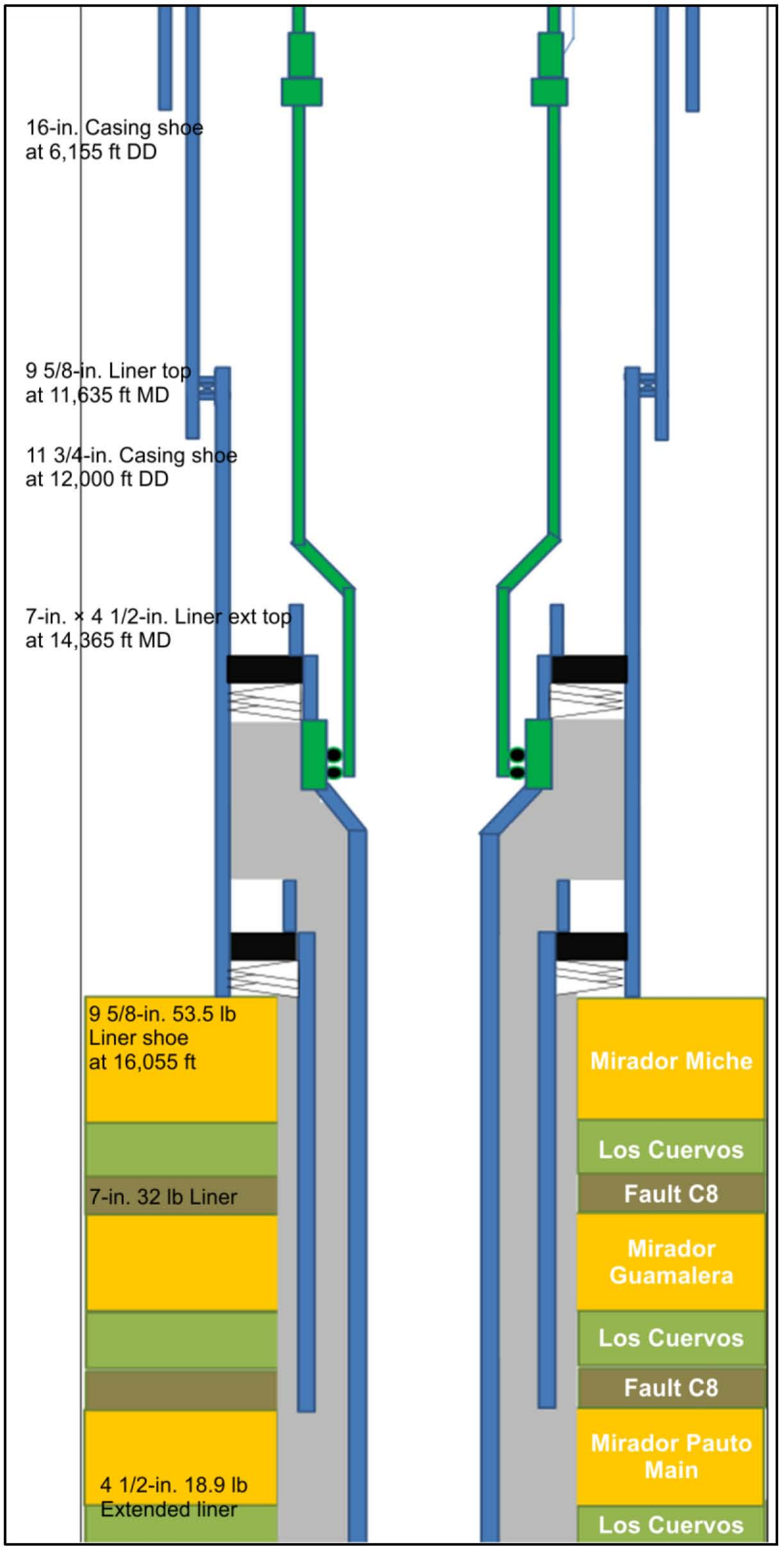

Figure 1—Well schematic.

During a perforation treatment using CT with a 70-ft BHA, the gun system became stuck, and it was not possible to move the pipe free after gun detonation. Sixteen attempts using various pressures, fluids, and velocity conditions were executed to release the BHA. Because of the increased fatigue from cycling of the pipe and lack of pipe movement observed, it was decided to activate the hydraulic disconnect and release the CT, leaving 56 ft of BHA in the 4.5-in.liner at 18,592 ft coiled-tubing depth corrected (ctdc) (depth referenced by the operator base profile log) (Fig. 2). As a result of the fish characteristics, in terms of outer diameter (OD) and length, the well production was reduced to 1,938 BOPD and 22.1 MMscf/D.

#	#	Description		OD in.	Length in.	Connection Top	Connection Bottom
1	1	**Fishing Neck**					
		Tensile (lbf)	45,000	2.120	1.14	175-in. CT pipe	1 1/2-in. AMMT pin
2	2	**Crossover**					
		Tensile (lbf)	53,000	2.875	6.50	1 1/2-in. AMMT box	2.375-in. EUE pin
3	3	**Pressure Relief Sub**					
		Tensile (lbf)	135,000	3.060	4.92	2.375-in. EUE box	2.375-in. EUE pin
4	4	**Model KVII 2.375 in.**					
		Tensile (lbf)	145,000	2.750	16.44	2.375-in. EUE box	2.375-in. EUE pin
5	5	**Gun Section**					
		Tensile (lbf)	141,000	2.875	284.16	2.375-in. EUE box	2.375-in. EUE pin
6	6	**EDA 3 3/8 in.**					
		Tensile (lbf)	141,000	3.360	96.48	2.375-in. EUE box	2.375-in. EUE pin
7	7	**Gun Section**					
		Tensile (lbf)	141,000	2.875	268.20	2.375-in. EUE box	Bull plug

Length (in.)	677.84
Length (ft)	56.49
Max. OD (in.)	3.360

Figure 2—Fish conditions.

Because of the production impact, a fishing intervention was planned using conventional CT. The first BHA used to recover the fish was comprised as follows:

- **CT Connector:** connects the CT with the BHA (OD: 2.44 in.).
- **Motorhead Assembly:** a compact tool incorporating a flapper valve to prevent fluid flowback through the tubing to the surface, hydraulic disconnect used as an emergency option to enable the retrieval of the tubing, and a circulation port used to enable circulation through the tool after a ball is dropped. (Vera et al. 2018b). Additionally, a rupture disk with a differential pressure of 7,500 psi was installed.
- **Bidirectional Impact Hammer:** delivers both upward and downward impact up to 1,000 times per minute. This jarring action with constant overpull is similar to the action created by a vibratory extractor.

- **Flow-Release GS Spear:** used to latch the fish internally. Can relatch the fishneck multiple times.

With the described BHA, a dry tag was performed to latch the fish. The normal weight of the CT was 54,000 lbm during pulling out of hole (POOH). When the fish was not latched, the weight remainedat54,000 lbm, but when the fish was hooked to recover it, the weight increased up to 75,000 lbm (maximum weight available to avoid any failure in the pipe based on the software results). Several attempts were performed to recover the fish without success (Fig. 3). Before the fishing intervention, it was evidenced that the top of fish was located at 18,567 ft (depth in tension, without elongation effects).After several attempts to recover the fish, it was evidenced that the same reference (flag on the CT) to the top of fish was located at 18,536 ft. With this result, it was concluded that during the first run, the fish moved from 18,567 to 18,536 ft. Even if the depth was not correlated, the operating company concluded that the fish moved 31 ft.

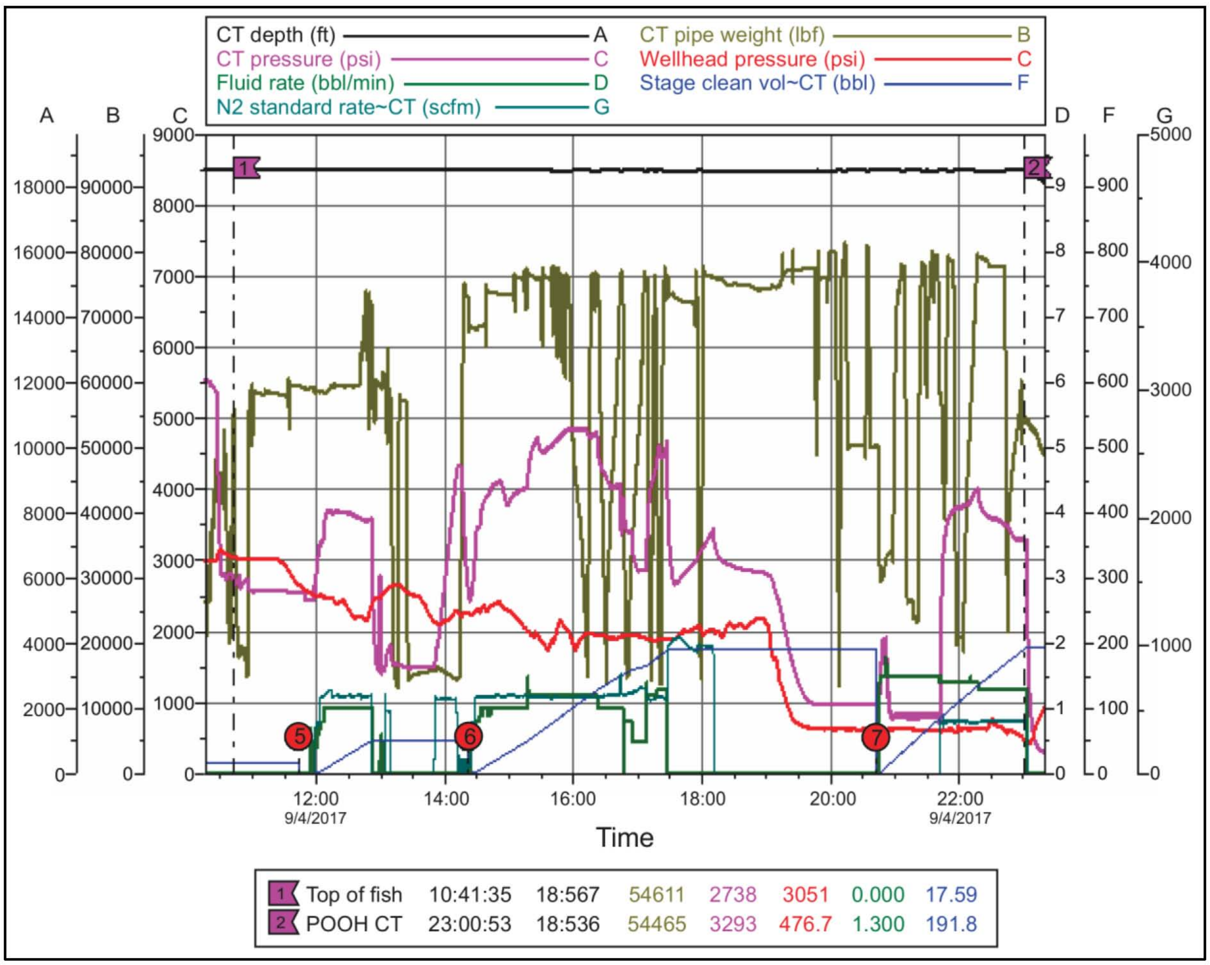

Figure 3—Conventional fishing operation with BHA Configuration No.1.

At this point, it appeared possible to move the fish. A second run was planned using conventional CT and a BHA composed of a CT connector, motorhead assembly, and the following additional tools:

- **Vibration Tool:** downhole vibratory tool that creates an oscillating axial force in the workstring.
- **Overshot:**an external catch tool used to recover the fish at surface.

Using this BHA configuration, a dry tag was performed to latch the fish. Twenty barrels of acid were pumped, and several attempts were performed to recover the fish without success. Before the fishing intervention, it was evidenced that the top of fish was located at 18,554 ft. After several attempts to recover the fish, it was observed that at the same reference (flag on the CT), the top of fish was located at 18,502 ft (Fig. 4).

As a result, it was concluded that during the second run, the fish moved from 18,554 to 18,502 ft. Even if the depth was not correlated, the operating company concluded that the fish moved an additional 52 ft.

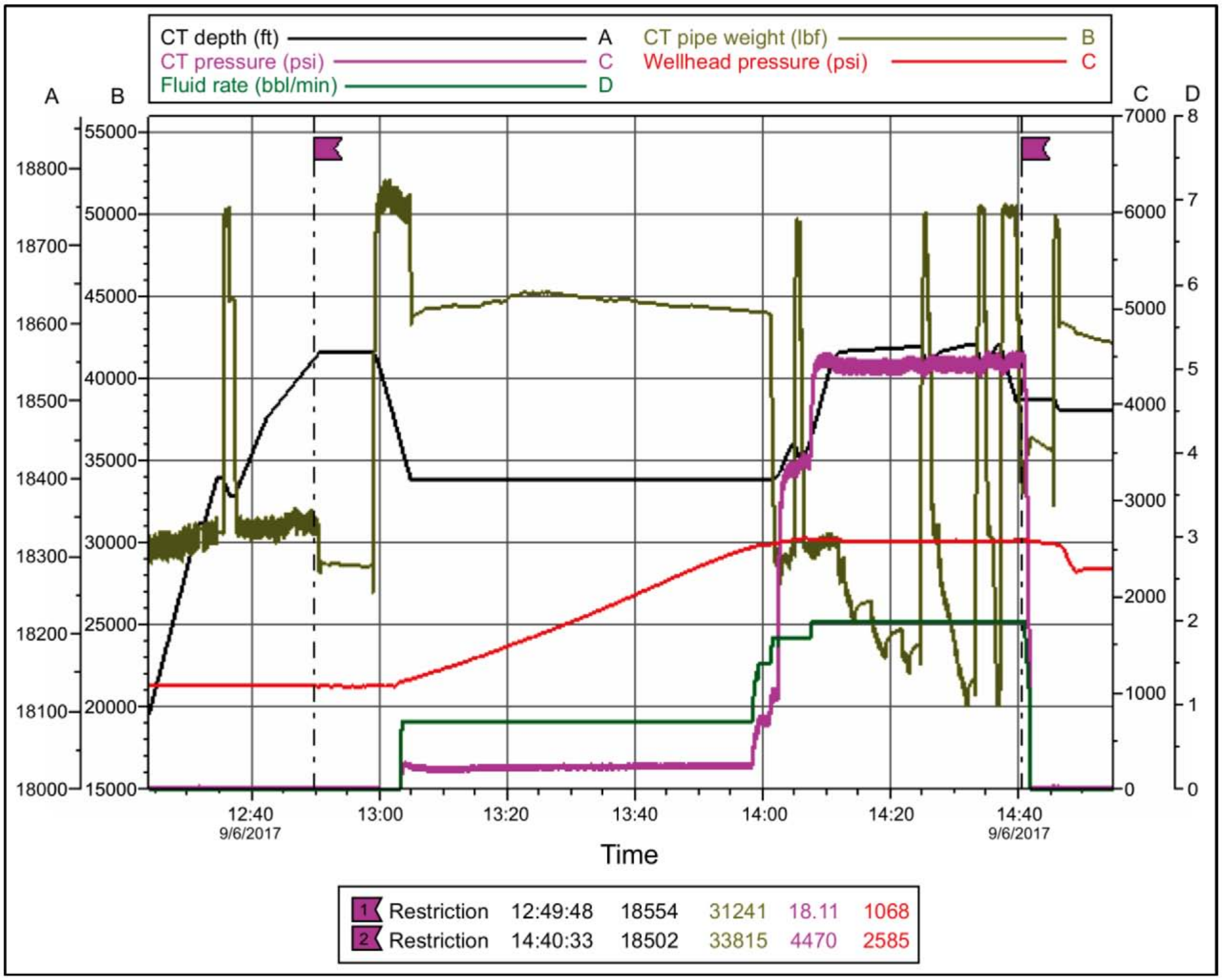

Figure 4—Conventional fishing operation with BHA Configuration No.2.

At this point, it was believed that the fish moved 83 ft in total. A third run was planned using conventional CT and a BHA composed of a CT connector, motorhead assembly, and the following additional tools:

- **Hydraulic Jar:** provides impact force to help pull the tools loose. As the jar is pulled in tension, the system stores energy and the continued upward pull moves, creating an impact force that exceeds the tension necessary to pull the tubing alone. The force supplied depends on the force applied at the tool.
- **Flow Release GS Spear:** used to latch the fish internally. Can relatch the fishneck multiple times.

The CT was displaced with nitrogen to increase the jarring force available at the fish. With the described BHA, a dry tag was performed to latch the fish. The normal weight of the CT was 41,000 lbm during POOH. The fish was latched, and the weight increased to 55,000 lbm to allow the jar action without affecting the integrity of the fishing neck.(fishing neck tensile rating: 45,000 lbm). After the jar action ended, CT continued POOH, and the weight increased to 75,000 lbm. Twenty attempts were performed with various overpull values, several velocities, and different wellhead pressures (WHPs) (Fig. 5).

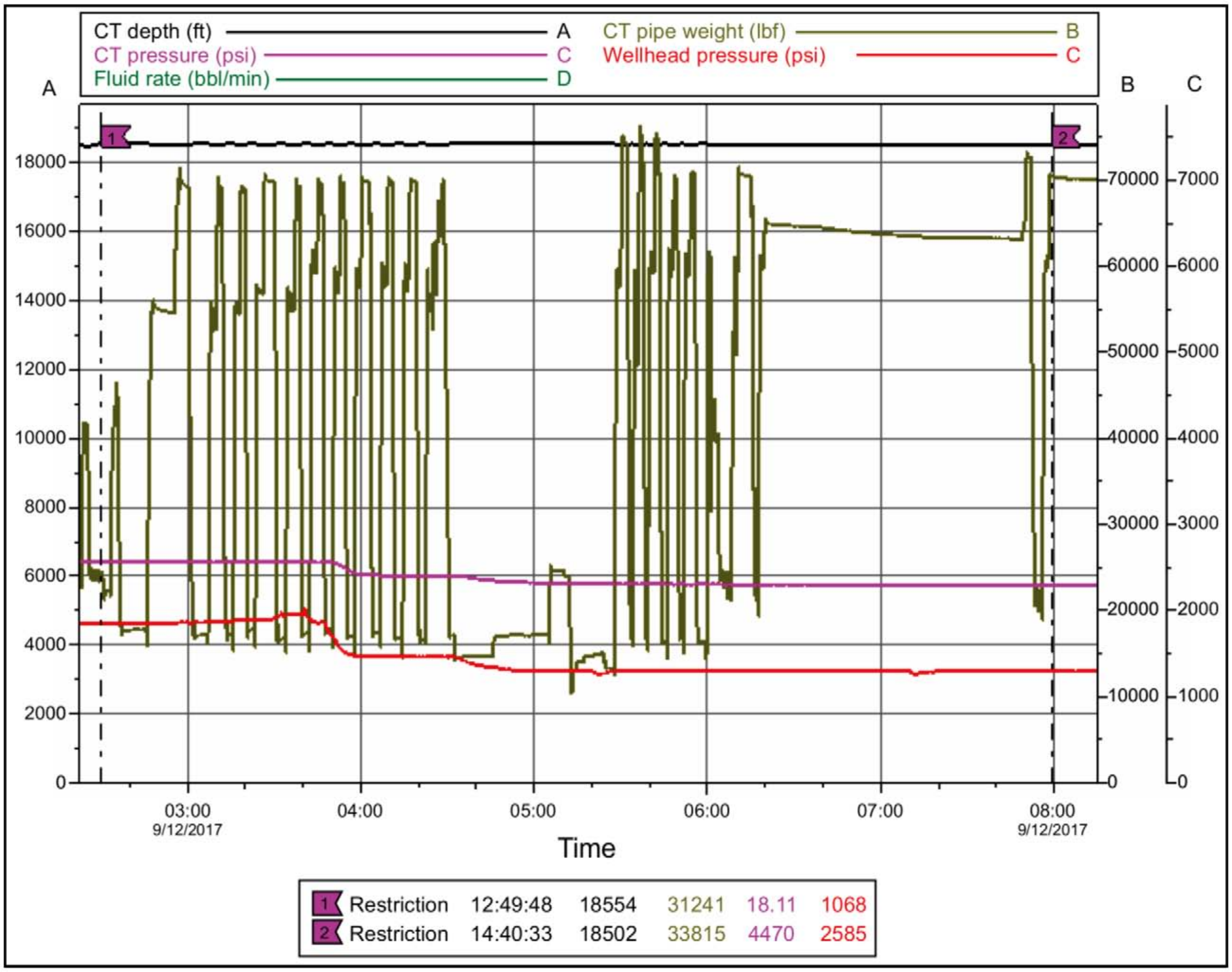

Figure 5—Conventional fishing operation with BHA Configuration No. 3.

Before the fishing intervention, it was evidenced that the top of fish was located at 18,554 ft. After several attempts to recover the fish, it was evidenced that at the same reference (flag on the CT), the top of fish was located at 18,515 ft. With this result, it was concluded that during the second run, the fish moved from 18,554 to 18,515 ft. Even if the depth was not correlated, the operating company concluded that the fish moved another 39 ft.

It was believed that, after the three interventions, the fish moved 122 ft. Two additional runs were executed with the same results but without any additional production increase from the well. The fishing intervention was evaluated and the following questions were generated:

- Whether the force transmitted from surface to the end of the CT real. At this point, the transmission force was calculated using software.
- Whether the fish actually moved and, if so, by how many feet, even though the displacement of the CT was verified with an electronic depth counter, mechanical depth counter, and some flags performed in the pipe.
- Which BHA performed the intervention most efficiently.
- Whether the fishing BHA worked as expected.

Because of these concerns about the fishing operation, an intervention using the real-time hybrid CT service and a robust tool was planned to resolve all uncertainties through a unique and definitive intervention that would allow recovery of the fish.

Operational Planning

The operation was planned to be delivered in two main stages. The purpose of the first stage was to verify downhole parameters using the robust tool that incorporated multiple sensors in the BHA but additionally had the capability to continuously power this tool to stay as long as needed in the well. Presently, this can be performed with a hybrid system (fiber-optic and electric cable), for which no battery is required, which also makes it possible to transmit data and communicate with and power tools from the surface.

Once the downhole data were collected with precision and confidence, they was analyzed to continue with the second stage of the operation, which was focused on recovering the fish with a proper BHA.

Development of the First Stage

Equipment Used

Real-Time Hybrid CT Service. A 4.0 mm encapsulated hybrid cable composed of multiple fiber-optic lines and one electric conductor with wireline capabilities is installed in a 2.00-in. OD CT string. This noninvasive encapsulated cable allows the system to be compatible with any CT operations onshore and offshore because its weight does not significantly affect the overall pipe weight and it is resistant to corrosion and abrasion, allowing any type of fluid to be pumped through the pipe and cable annulus at high rates and pressures. Additionally, it enables the system to be open architecture, allowing multiple wireline systems to be integrated and any mechanical tool, even if a ball drop capability is required.

BHA. The BHA used during this operation was composed of the following:

- **CT Connector:** connects the CT with the BHA (OD: 2.44 in.).
- **Real-Time Hybrid Sensor BHA:** a robust modular system equipped with a cable head that includes a cable cutter; a motorhead assembly composed of a rupture disk, flapper valve, and hydraulic disconnect; an ultra-compact sensor module with gamma ray, CCL, internal and external pressure, and internal and external temperature; WOB; acceleration; inclination; tool face; and vibration. The final design included the hybrid-sensor BHA module having an intervention adapter to connect all mechanical tools (for logging services, a wireline adapter could be connected). This module has the ability to measure bottomhole data in wells having temperatures up to 350°F and is rated to 15,000 psi absolute pressure (OD: 3.375 in.).
- **Hydraulic Jar:**provides impact force to help pull the tools loose; the same one used in the third run.
- **Hydraulic Disconnect:**releases the tubing from other downhole tools made up below it and is activated by a dropped ball and tubing pressure; it is used as an emergency release (OD: 2.875 in.).
- **Circulation Sub:**allows circulation at high rates through ports on the side of the tool after a ball is dropped. Any fluid can be pumped through the ports (OD: 2.875 in.).
- **Flow-Release GS Spear:**used to latch the fish internally. Can relatch the fishneck multiple times.

Operation Execution

The equipment described previously was run in hole(RIH) and correlation was made with the operator base profile log. A dry tag was performed and the top of fish was identified at 18,592 ft ctdc (Fig. 6). All movement described in the background section based on CT flags and electronic and mechanical depth counters was not accurate resulting from elongation of the CT, skewing the actual bottomhole information. All previous runs did not move the fish.

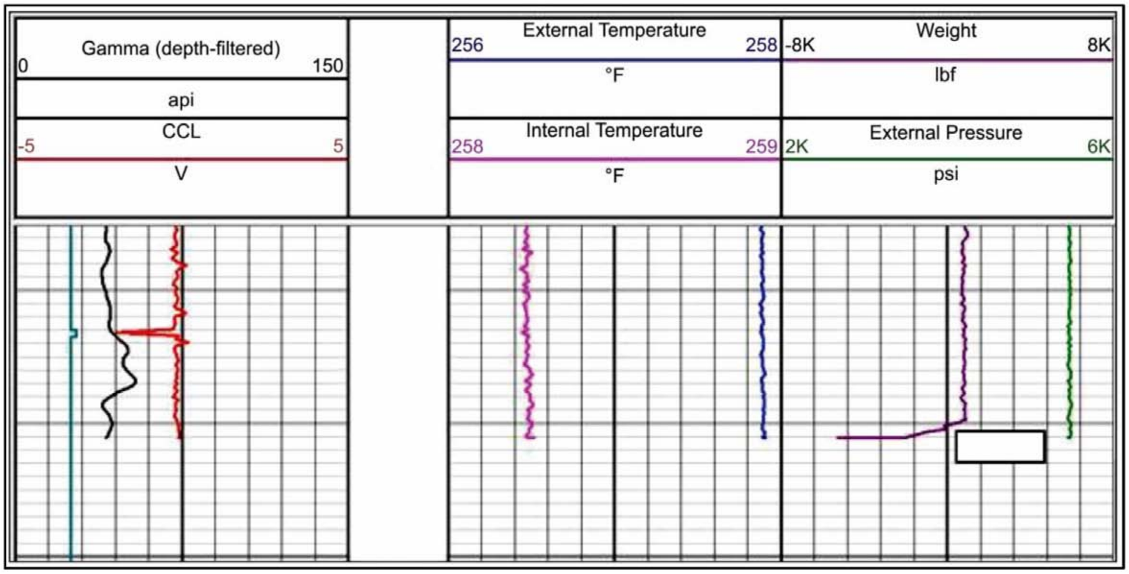

Figure 6—Top of fish dry tag.

To better understand what was occurring downhole in real time during the fishing intervention, six attempts to recover the fish were performed using the BHA for the first stage. Fig.7 shows one of these attempts. Blue, red, pink, and black curves represent the behavior at surface for each parameter. The remaining curve shows the data received from the hybrid-sensor BHA to the control cab.

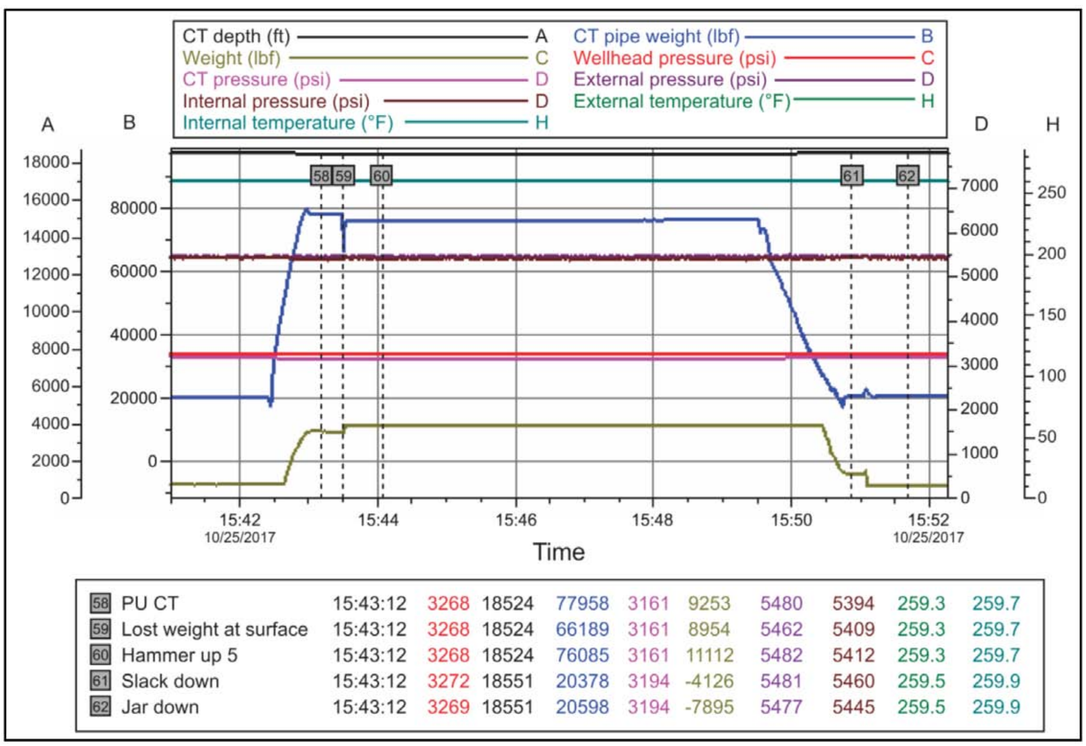

Figure 7—Fishing attempt with bottomhole data.

During a fishing intervention, the most important variable is weight (tension/compression). Following the behavior of the blue and gold curve, it is evident that when the CT was pulled up to 78,000 lbm (measured weight at surface), 10,000 lbm were applied at the end of the pipe. After the system jarred up, it was evident that the downhole weight increase only 2,000 lbm. Because the sensors are located above the jar, it was not possible to identify whether the increased weight value was real, associated with the jar. In addition, it was not possible to measure the impact transmitted to the fishing neck.

After 5 minutes with the pipe in tension, 4,000 lbm at the bottomhole were applied to evaluate the down-acting force of the hydraulic jar, and an increase of 3,000 lbm was observed.

Because of the fatigue increase at the same point, and all six attempts showed the same behavior as in Fig.7, it was determined that the force generated by the hydraulic jar was not sufficient to recover the fish. It was decided to POOH to surface and evaluate the downhole parameter data obtained.

Job Parameters Analysis: Real-Time Data vs. Simulated

Increasing values, such as wellhead pressure, reel back tension, friction coefficient, and stripper friction, will affect the surface weight reading. In this case, the friction coefficient values (between the CT string and completion tubular) were under review to calibrate the computational model.

Once the friction coefficient values were identified, simulations were performed at the reference depth of18,592 ft. Fig.8 shows the maximum pickup force that can be applied in certain conditions with CT at a specific depth. When reaching the maximum pickup at surface (surface weight), it is possible to observe how much force is present at the end of the CT (pickup at end) based on the yield of the CT string and the conditions simulated. The information in Fig. 8 helps set the minimum tension test for the CT connector and also verify the maximum force that can be applied downhole to open or close downhole valves, for example. However, when fishing, it helps to determine what the limit at the surface would be and compare it to the bottom to establish how much downhole force can be applied to overpull the jar.

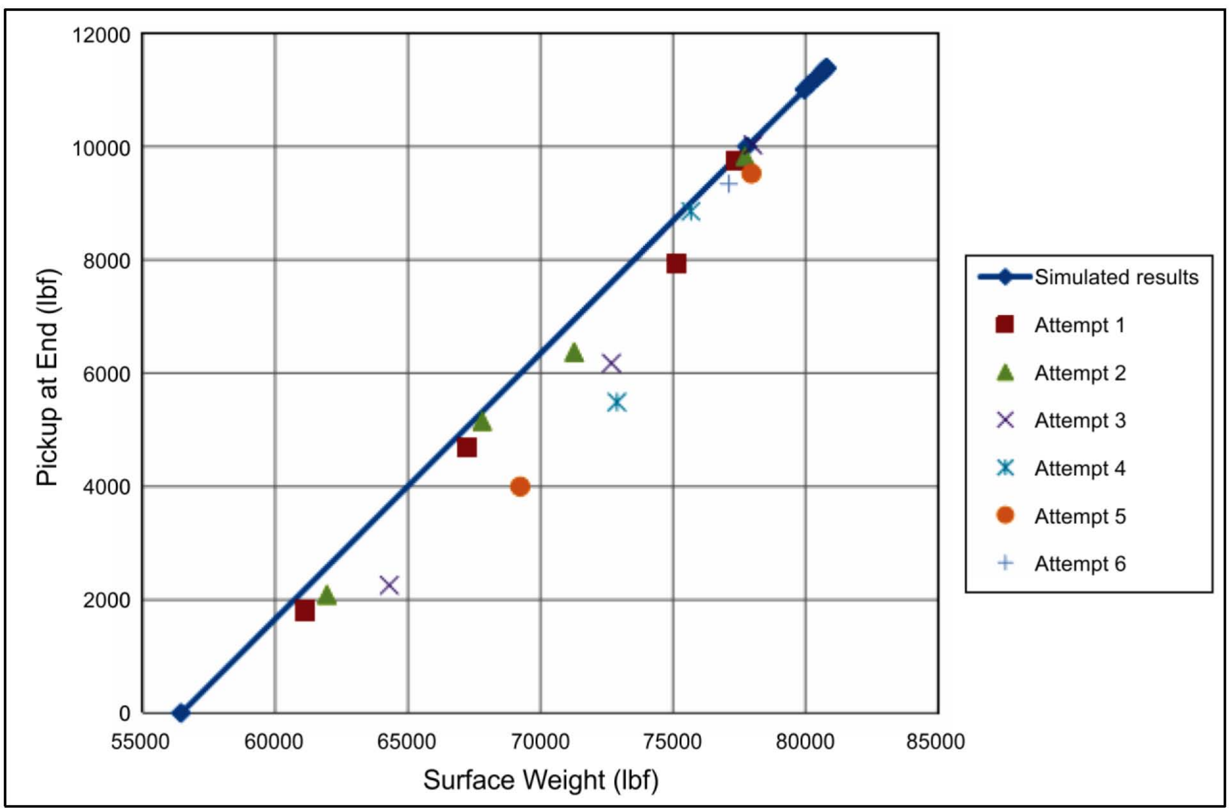

Figure 8—Fishing attempt with bottomhole data.

The continuous blue curve shows the data obtained by the software, and the points shown, represent values for each cycle of jarring up obtained during the intervention using the real-time hybrid service. The first point of the blue curve represents the weight of the pipe at the reference depth with a CT pressure of

3,180 psi and a WHP of 3,259 psi. At such pressure conditions, the actual weight of the CT string reading during the intervention was 56,830 lbf, which can be compared with simulated estimates from the software, having a corresponding value of 56,450 lbf. The delta of those values correspond to an error of 0.66%.

Based on the results, this software provides high-quality simulations, which provides confidence in force calculations for fatigue management.

The last point of the blue curve represents the maximum weight that can be applied to help avoid failure in the CT string. During the fishing intervention, the maximum weight available was never reached. Therefore, the data were compared with the maximum weight reached before the hydraulic jar was actioned. This point corresponds to the last point of each attempt to release the fish on Fig.8. Table 1 shows the last point acquired by the real-time hybrid service and the data obtained by the software with the percent error associated.

Table 1—Comparison between tension on bottom with a real-time hybrid service and software.

Attempt to Release the Fish	Weight at Surface (lbm)	Pickup at End Acquired by the Real-Time Hybrid Service (lbm)	Pickup at End Acquired by the Software(lbm)	% Error Associated
1	77,376.18	9,743.885	9,778.889	0.359241
2	77,736.63	9,824.946	9,947.325	1.24559
3	78,027.68	10,023.83	10,083.33	0.593671
4	75,685.86	8,854.593	8,989.002	1.517962
5	77,973.59	9,521.623	10,058.06	5.633847
6	77,123.18	9,335.029	9,660.662	3.488287

Taking the data acquired by the real-time hybrid service as a reference, the error of the force transmitted to the end of the CT obtained by the software was less than 6%. In Fig.8, the values acquired in the section between the weight of the pipe*(pipe weight in neutral position)* and the maximum weight while pulling *(pipe weight in tension)*have a deviation when compared to the data simulated by the software, which is a result of the difference between the CT movement and the speed of data being transmitted from the tool to surface *(when information from the memory of the tool was evaluated, it showed the tendency of error percentage)*.For this application, the pickup transmitted at the end of the CT at lower surface weights was not evaluated because of the need for additional cycles at the same point, and the purpose of the operation was to understand the data during the maximum pull, which was the most favorable scenario for the fishing intervention.

At this point, only the data transmitted by the injector from surface to the BHA were analyzed, and it was concluded that using the CT string available, it was possible to pull the fish to ~10,000 lbm.

The hydraulic jar should generate an additional overpull. Because the sensors are located above the hydraulic jar, it was not possible to measure the actual increase of tension generated by the jar. Only 2,000lbfadditional force was observed by the real-time hybrid service.

With this information, it was concluded that more force and impact to the fish were necessary to release the obstruction. Therefore, a second stage was planned and executed.

Development of the Second Stage

During this stage, the real-time hybrid service was not used because the purpose was to work with the fish. The same CT from the background section was used, and based on simulations with the confirmed input force by the CT, a new BHA capable of generating more force at the end was designed to release the fish.

BHA

The BHA used during this operation consisted of the following:

- **CT Connector:** connects the CT with the BHA (OD: 2.44 in.).
- **Flapper Valve:** prevents fluid flowback through the tubing to surface (OD: 2.88 in.).
- **Intensifier:** supplies intensified impacts during jarring operations (OD: 2.88 in.).
- **Weight Bar:** can increase the amount of impact applied at the fish while running in tandem with a jar and intensifier (OD: 2.75 in.).
- **Hydraulic Jar:** provides impact force to help pull the tools loose; the same as the one used during the third run (OD: 2.88 in.).
- **Hydraulic Disconnect:** releases the tubing from other downhole tools made up below it and is activated by dropping a ball and tubing pressure; it is used as an emergency release (OD: 2.125 in.).
- **Circulation Sub:** allows circulation at high rates through ports on the side of the tool after a ball is dropped. Any fluid can be pumped through the ports (OD: 2.125 in.).
- **Flow-Release GS Spear:** used to latch the fish internally. Can relatch the fishneck multiple times (OD: 2.125 in.).

Operation Execution

CT was displaced with nitrogen to increase the jarring force available at the fish. Using the BHA discussed, a dry tag was performed to latch the fish. Five attempts to recover the fish were performed unsuccessfully. During the sixth attempt, the fish was freed and well production was recovered (Fig.9).

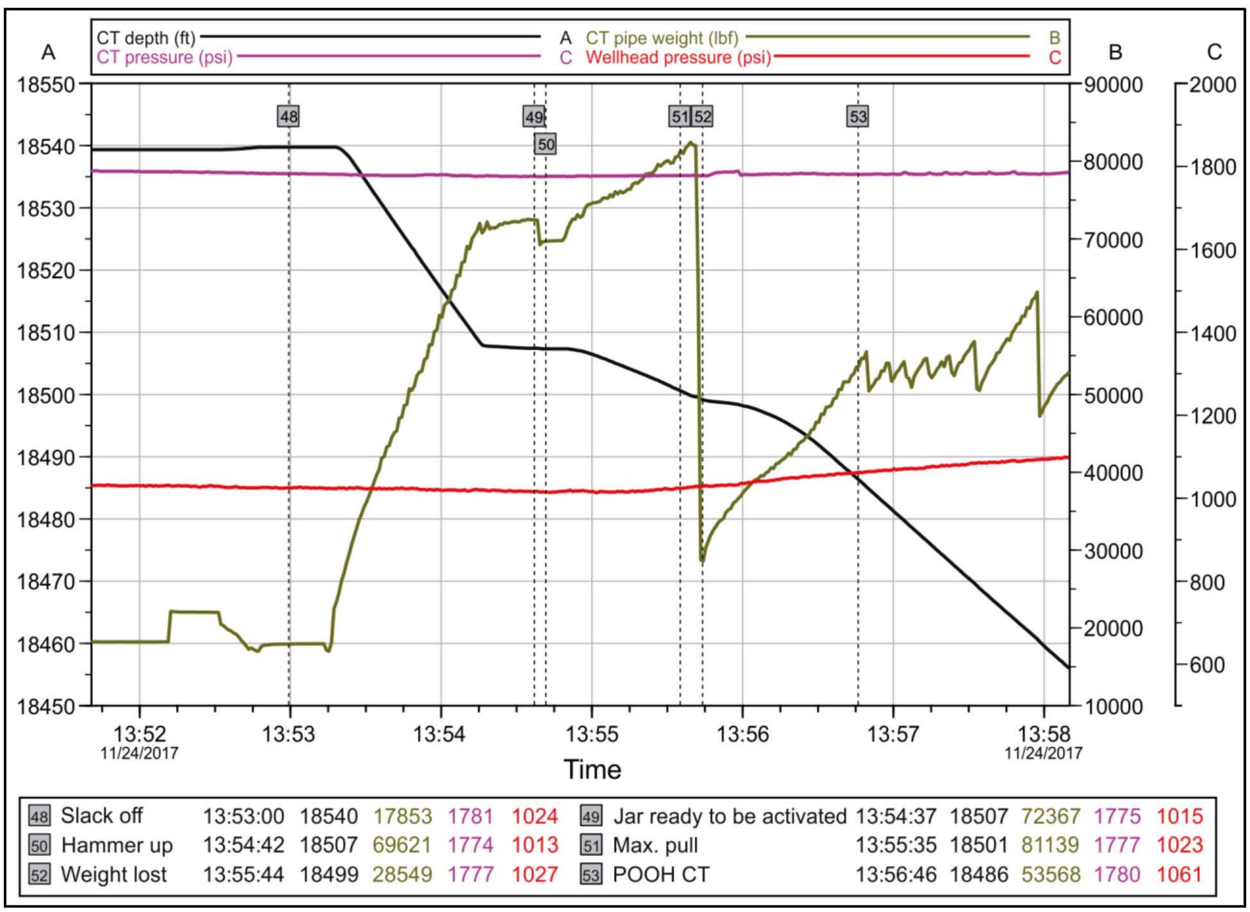

Figure 9—Fishing operation with appropriate BHA.

After the intervention, well production returned to 3,489 BOPD and 41.9 MMscf/D with 2.11% BSW.

Conclusions

The following conclusions are a result of this work:

- The real-time hybrid service helped the operator understand the transmission of forces downhole through the string and BHA. In this study, this advantage enabled the operator to identify the best BHA to release the fish.
- Use of the real-time hybrid service made it possible to evaluate and verify whether the data acquired by software related to the force transmission in the CT were reliable and accurate.
- The accuracy and reliability demonstrated by the CT simulation software increased operator confidence in all simulations performed with the software for future CT operations.
- During a fishing operation, the downhole fish can appear to be moving in the well as a result of movement of the counter depth at surface and pipe elongation. Incorrect interpretations can result in additional runs performed without any benefit.
- Because the sensors are located above the hydraulic jar, it was not possible to evaluate the actual force increase generated by the tool. Additionally, the impact force was not measured during the verification parameter analysis.
- Production of the well recovered from 1,938 BOPD, 22.1MMscf/D and 1.22% BSW to 3,489 BOPD, 41.9 MMscf/D, and 2.11% BSW as a result of the successful yet challenging fishing intervention.
- Many attempts to evaluate downhole conditions can be performed without constraints on time because of the continuous power supply from surface of the real-time hybrid service.

Acknowledgments

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Nomenclature

BHA	*bottomhole assembly*
BOPD	*barrels of oil per day*
BSW	*basic sediment and water*
CCL	*casing collar locator*
CT	*coiled tubing*
ctdc	*coiled tubing depth corrected*
ft	*feet*
MD	*measured depth*
MMscf/D	*million standard cubic feet per day*
OD	*outer diameter*
POOH	*pull out of hole*
TVD	*true vertical depth*
WHP	*wellhead pressure*

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