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Hydraulic Coiled Tubing Tractor Technology Extends the Accessibility of Coiled Tubing in Horizontal Wells, Allowing Better Well Intervention – Case Study

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ABSTRACT: Recent advances in drilling technology have resulted in longer horizontal wells and have increased the complexity of well completion; the well intervention is becoming more challenging. Conventional techniques are no more adequate to access in long openhole horizontal sections when using coiled tubing to perform intervention works such as stimulations, logging and zonal isolation. This essay was created to assess the capability of a coiled tubing string to reach the desired depth in a projected long horizontal well. The scope of this essay is to provide a complete set of simulations to predict the tubing forces for two proposed different diameters of openhole section. Such simulations can serve as guidelines for completing the well.

KEYWORDS: Coiled tubing, accessibility, friction coefficient, lockup, fatigue, openhole, cased hole, completion, surface weight

I. INTRODUCTION

Coiled tubing (CT) has many applications in the oil and gas industry and has been used to service wells since the early 1960s. Continuous improvements in technology and reliability mean that CT is now a common intervention technique. It is the ability to operate in live wells, relatively quickly and easily, that makes CT an obvious choice for many interventions, especially where there is a requirement to pump fluids. A modern CT unit is capable of many well intervention applications [5]. CT is a long, continuous length of metal pipe wound on a spool used to pump chemicals for circulation, logging, drilling, cementing, wellbore cleanout, acidizing, hydraulic fracturing, sand control and other assignments that involve pumping fluids at high temperatures and high salinity. But due to the limitations of CT size and weight, it has no ability to operate when the depth is over 5000-m.

II. ACCESSIBILITY OF THE CT INTO THE WELL – LOCKUP DEPTH

For a well to be accessible with CT, the coiled tubing need to be run to the end of the horizontal section and no lockup should happen before reaching TD. Lockup is a condition that may occur when a CT string is running into a horizontal or highly deviated wellbore.[8] Lock-up occurs when the frictional force encountered by the coiled tubing string running on the wellbore tubular reaches a critical point. When axial compression forces over critical value are applied to CT, the CT will first buckle into a sinusoidal wave shape, although more tubing may be injected into the wellbore, the end of the tool string cannot be moved farther into the wellbore, hence, the applied weight on surface cannot be transmitted to the end of a CT string and consequently no progress into the horizontal section is possible. As the compressive force increases further, it will ultimately deform into a helix. CT simulation software can approximately predict the depth at which this lockup is reached and whether it will occur, however, the real lockup point can only be found when the CT tubing is run into the hole. [2, 3, 4] Such simulations are often used in the planning stage of a CT intervention to decide on type of coiled tubing pipe to be used (diameter and thickness). The following factors are taken into account in the simulation: well trajectory, CT pipe variables (O.D, Thickness, strength, and length), well bore diameter, friction coefficients (cased/openhole), well fluid type, temperature, pressure, and well head flowing conditions[8, 9]. Many techniques can enhance the accessibility of a CT string into wellbore: use of a larger CT pipe (more weight), pipe strengtheners, vibrating tools, pumping of nitrogen, pumping of friction reducer, tractors or a combination of the above mentioned. [10]

III. FRICTION REDUCERS – COEFFICIENT OF FRICTION

A friction reducer is an additive, generally in slurry or liquid form, used to reduce the friction forces experienced by tools and tubulars in the wellbore. Friction reducers are routinely used in horizontal and highly deviated wellbores where the friction forces limit the passage of tools along the wellbore. [12]

The coefficient of friction (CoF) is a very important dimensionless scalar value that characterizes the surface-to-surface interaction. Detailed CT friction modelling becomes crucial in the planning stage to ensure successful job predictability. However, current numerical simulators consider constant CoFs that are determined from similar operations without taking into account the effects of the operational and downhole parameters on the CoF for a specific operation. The exact value of the CoF valid to a situation is a function of many things, including fluid type (inside of well and Coiled Tubing) and composition, formation type (in open hole) casing material and condition and tubing material and condition (roughness). At a single point in time, the mud type and composition in the well are constant but significant changes may be taking place in portions of both cased and open hole. Thus, in certain cases, it may be necessary to use two friction factors, one for the CT–casing interaction and one for the CT–formation interaction. [5, 6, 7, 9, 11]

IV. HYDRAULIC COILED TUBING TRACTOR

The CT-tractor is a hydraulically powered device that generates downhole movement, a device that generates a concentrated traction force downhole when activated. This force is needed to pull the CT in highly deviated or horizontal section of the hole. The Tractor consists of two gripper and piston assemblies – one on the front and one at the back. A control unit, positioned between the assemblies, diverts fluid to each assembly in a synchronized manner. To start the Tractor, the operator increases fluid flow until the pressure to the Tractor exceeds a predetermined set point. The fluid drives the hydraulic system and moves the tractor forward. Traction occurs when the pressurized fluid is distributed to the forward gripper/arm, which causes it to expand and engage the inside diameter of tubing/casing/openhole, a piston is activated and the force applied by the tractor moves the string forward and pushing the downhole equipment ahead of it. This sequence is then repeated, activating the second assembly. (One assembly engages as the other disengages). The resulting motion is similar to that of an inchworm, providing continuous forward movement without damaging the casing or formation. The Tractor will travel at the maximum speed with the maximum pulling force possible for the available differential pressure. The rate of advancement down the wellbore is controlled by the rate of feed from the coiled tubing injector. The advantage of using a CT-tractor at the end of coiled tubing is that the tractor provides a concentrate downhole force that can delay or prevent lockup by pulling the coiled tubing from its end. This often results in improving well accessibility on ERW. It is thought that when the CT locks-up, a spiral type of form takes place at the end of the CT section; having a concentrated point load acting at the end of the CT will make this event unlikely thus improve the accessibility. The following are the main factors considered when selecting a CT-tractor. [11, 13]

- *Size:* Tractors exist in four nominal sizes: 2.125-in, 3.0-in, 3.125-in, 3.5-in and 4.7-in. The smallest ID restriction in the wellbore basically controls the selection of the tractor size to be used. The larger the tractor sizes the more force it will be capable of generating (from 3,200-lbf to 14,500-lbf). [8, 9, 13]
- *Grippers/Arms Configuration and Type*: The grippers/arms must be small enough to pass through the minimum ID restriction of the well and large enough to reach the biggest ID in the wellbore. For an OH operation normally the largest size of grippers available will be selected as the maximum hole diameter is often unknown and depends on the hole conditions and the type of formation. Grippers/Arms with optimized edge are used when tractoring in the open hole; this allows better traction in the open hole section. [8, 13]
- *Force Required*: Well Intervention simulation indicates the theoretical force required to reach TD. This must be compared to the force available from the tractor and a safety margin needs to be added. Previous experience has shown that it is often much more advantageous to run two Tractors in tandem in an open hole situation as this will provide more force and more grip especially in situations where a washed-out section of the well has to be overcome. Theoretically, when two Tractors are run in tandem, the force available multiplies by two.[1, 8, 9]

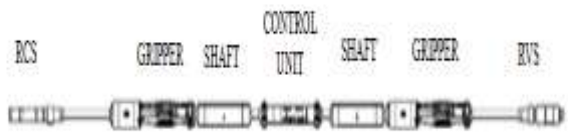


Figure 1: CT – Tractor [WWT Technical Brochure]

V. ACCESSIBILITY SIMULATIONS RESULTS

An important part of the evaluation for completing an ERW involves computer modeling of the CT operations, in this essay the objective of the simulation was to determine feasibility of CT operation for long horizontal wells and to estimate the CT equipment requirements (tractoring force applied at the end of the CT string). A commercial Simulator was used to predict the tubing forces. The simulations were completed considering the following cases:

a) The surveys for the ERW which provided: MD, TVD and trajectory of the well
b) Completion: Production tubing 5.5 inches O.D and 23.5 Lb/ft weight.

Openhole section two cases: 6.0 inches and 8.5 inches.

A. Well considerations

The projected well is going to be drilled in the Middle East, is an oil producer with a horizontal section of around 14,050-ft, The Well has a bottomhole temperature (BHT) of 300°F and a bottomhole flowing pressure (BHFP) of 2,500 psi. The well will be completed with 5.5-in tubing in a 9.625-in. The Well will be completed as an extended reach horizontal openhole to a total depth (TD) of 24,260-ft and true vertical depth (TVD) of 10,560-ft. The OH section will be drilled from 13,900-ft to TD. The final diameter of the OH section will be decided after CT force analyses. This assay provided a set of simulations to predict the tubing forces for two different diameters of openhole section. Such simulations can serve as guidelines for completing the well. Table 1 shows the depths and proposed well configurations.

Table 1. Projected Well Configuration

Section	Top MD (ft)	Bottom MD (ft)	Length (ft)	O.D. (in)	I.D. (in)	Grade	Weight (Lb/ft)
Tubing	0	13,900	13,900	5.500	4.670	P–110	23
Casing	0	13,884	13,884	9.625	8.835	K–55	40
Open Hole – Case 1	13,900	24,260	10,360	-	**6.000**	-	-
Open Hole – Case II	13,900	24,260	10,360	-	**8.500**	-	-

B. Friction Coefficients

In current simulation, the default CoFs for cased holes, when no lubricant or friction reducing tools such as fluid hammer tools and tractors are used; vary from 0.24 to 0.30 or even higher.[7]

Table 2. Default Friction Coefficient assumed by the mathematical model

Section	Friction Coefficient during RIH	Friction Coefficient during POOH
Cased Hole	0.30	0.25
Open Hole	0.40	0.35

The use of chemical friction reducers has been utilized to increase the CT reach. Metal-Metal contact friction can be reduced creating a low friction film between the CT and cased/OH surfaces, thus reducing the drag force on the CT and enhancing penetration.

Table 3. Friction coefficients with friction reducer*

Section	Friction Coefficient during RIH	Friction Coefficient during POOH
Cased Hole	0.24	0.18
Open Hole	0.30	0.24

*With friction reducer it is possible to reduce in a 20% or more the friction coefficients. The friction coefficient of 0.30 and 0.24 were respectively considered based on extensive experience running in open hole section in Saudi Arabia

C. Coiled Tubing String

A 2.375-in O.D tapered wall thickness coiled tubing string was used in the simulations, the Length of the string is 31,615-ft, and the CT is to be 90,000 psi yield strength. Table 4 shows the CT string construction, with a wall thickness of 0.204-in at the top tapered to 0.175-in at the bottom of the string.

VI. RESULTS AND FORCE ANALYSES

In this essay it was evaluated if the CT-string can reach the target depth in the well under study. Simulations were carried out using a dedicated software package that considers several pieces of wellbore, directional and tentative final completion data. Table 5 shows the necessary input data used to perform the simulation for both OH section diameters. In all simulated cases presented in this paper a tractor size of $3^{1/8}$-in was used.

Table 4. Coiled tubing String Sections.

O.D (inches)	Start I.D. (inches)	End I.D. (inches)	Start Wall Thickness (inches)	End Wall Thickness (inches)	Section Length (ft)	Cumulative Length (ft)
2.375	1.967	1.967	0.204	0.204	7,110	7,110
2.375	1.967	1.927	0.204	0.224	165	7,275
2.375	1.927	1.927	0.224	0.224	530	7,805
2.375	1.927	1.903	0.224	0.236	100	7,905
2.375	1.903	1.903	0.236	0.236	2,610	10,515

2.375	1.903	1.927	0.236	0.224	110	10,625
2.375	1.927	1.927	0.224	0.224	3,655	14,280
2.375	1.927	1.967	0.224	0.204	155	14,435
2.375	1.967	1.967	0.204	0.204	3,845	18,280
2.375	1.967	2.025	0.204	0.175	185	18,465
2.375	2.025	2.025	0.175	0.175	740	19,205
2.375	2.025	2.063	0.175	0.156	165	19,370
2.375	2.063	2.063	0.156	0.156	855	20,225
2.375	2.063	2.107	0.156	0.134	125	20,350
2.375	2.107	2.107	0.134	0.134	11,25	31,615

A total of four scenarios were simulated using CT, table 6 and table 7 summarizes the theoretical lockup depth (Maximum depth reached by CT) predicted by a commercial well intervention software.

The Forces charts represent the weight versus stress that will be registered in the weight indicator when the coiled tubing string is RIH (tripping-in) and POOH (tripping-out) of the well. The Lockup curve indicates that if the surface weight at a certain depth registers a value equal to the lock up at that point, it means that the CT string cannot advance while descending into the well because the force exerted on the CT string cannot overcome the friction in the pipe and the other forces acting in the opposite direction to the movement of the CT string.

If the registered surface weight when coiled tubing is Tripping-in is always higher than the lockup weight; therefore no problems would be expected for the trip-in.

Table 5. Input Data for CT simulation.

Input Data	UOM	Run 1	Run 2	Run 3	Run 4
Cased Hole Friction Coefficient during RIH	-	0.30	0.24	0.30	0.24
Cased Hole Friction Coefficient during POOH	-	0.25	0.18	0.25	0.18
Open Hole Friction Coefficient during RIH	-	0.40	0.30	0.40	0.30
Open Hole Friction Coefficient during POOH	-	0.35	0.24	0.35	0.24
WHP	psi	1,000	1,000	1,000	1,000
Pumping rate	bpm	0	0	0	0
Fluid inside of CT an its density	ppg	KCl–8.7	KCl–8.7	KCl–8.7	KCl–8.7
Fluid inside of Well and its density	ppg	KCl–8.7	KCl–8.7	KCl–8.7	KCl–8.7
Stripper (stiffing box) Friction	lbf	500	500	500	500
Reel Back tension	lbf	700	700	700	700
It was used friction reducer?	-	Not	Yes	Not	Yes
It was used CT-Tractor?	-	Not	Not	Yes	Yes

Table 6. Output Data for CT weight Vs depth simulation considering 8.5 inches open hole section.

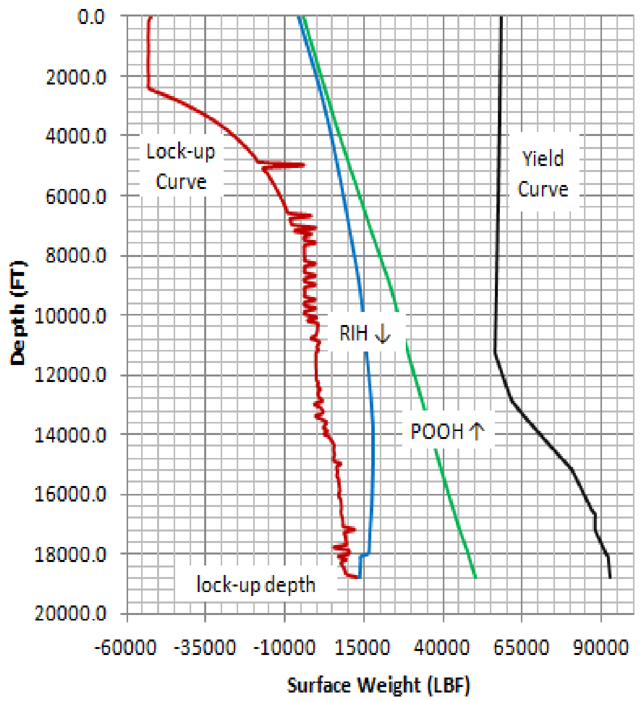
Output Data for 8.5 in Diameter OH section	UOM	Run 1	Run 2	Run 3	Run 4
Did lockup occur?	-	Yes	Yes	Not	Not
Lockup depth (Maximum depth reached by CT)	ft	17,900	19,200	24,260	24,260
Minimum Calculated Tractoring force to pull CT	lbf	0	0	8,700	5,100
Maximum Stress Factor	-	0.57	0.55	0.68	0.60

Table 7. Output Data for CT weigh Vs depth simulation considering 6 inches open hole section.

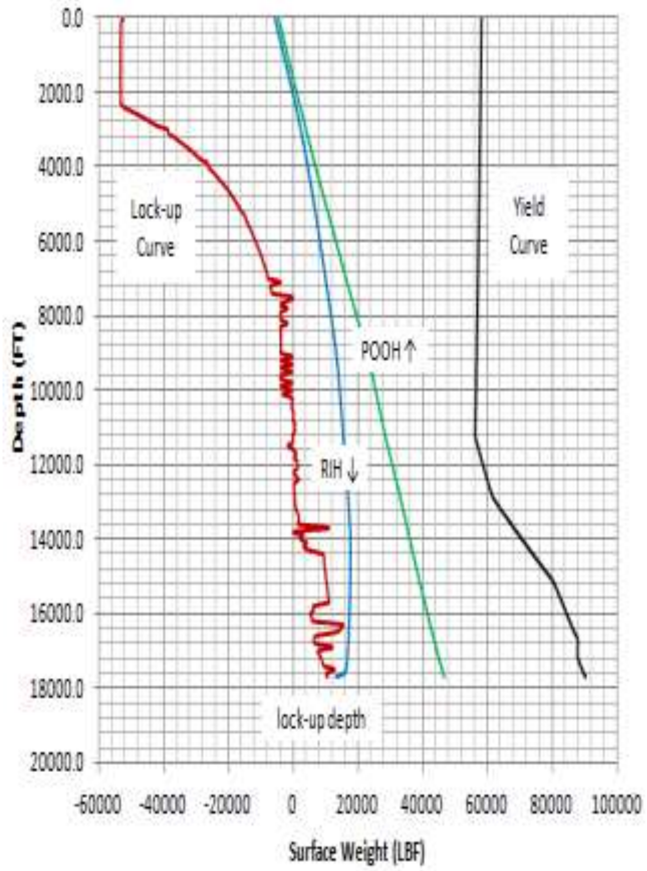
Output Data for 6 in Diameter OH section	UOM	Run 1	Run 2	Run 3	Run 4

Did lockup occur	-	Yes	Yes	Not	Not
Lockup depth (Maximum depth reached by CT)	ft	18,800	20,500	24,260	24,260
Minimum Calculated Tractoring force to pull CT	lbf	0	0	7,250	4,250
Maximum Stress Factor	-	0.52	0.50	0.61	0.54

Figure 1 shows the theoretical CT lockup for the well under study for both diameters of OH section. According to figure 2A and table 6 (run 1), the Maximum depth reached by CT is 17,900-ft when the diameter of the OH section is 8.5-in. As can be seen in figure 2B and table 7 (run 1) an improvement on the reach is observed with the 6-in open hole section option, if the open hole section is 6-in, the CT reach is increased by additional 1,000-ft before lockup in average, because the string has less area to deform inside the hole. In accordance with the field experience, actual lockup point can only be found when CT is run into the well; final lockup depth may vary depending on actual wellbore conditions.



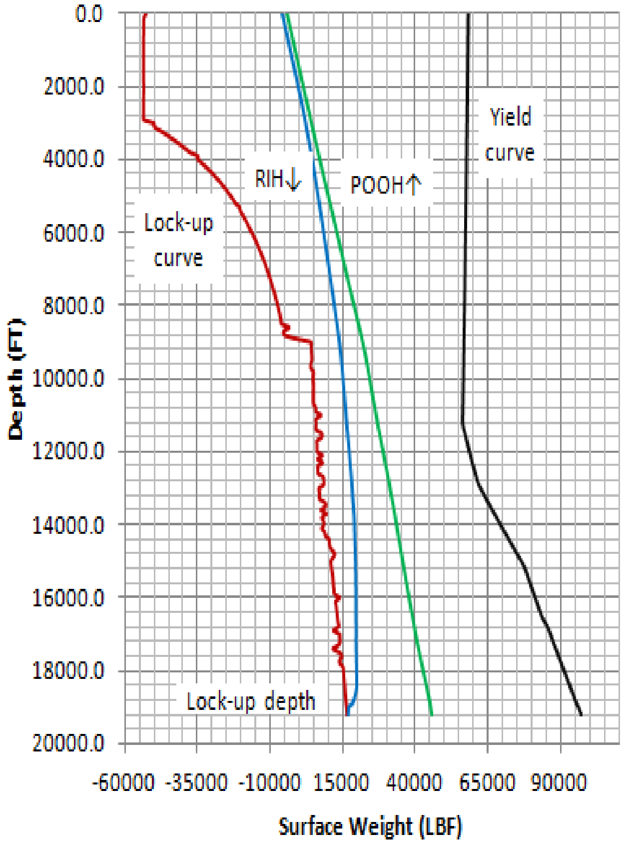
(A)



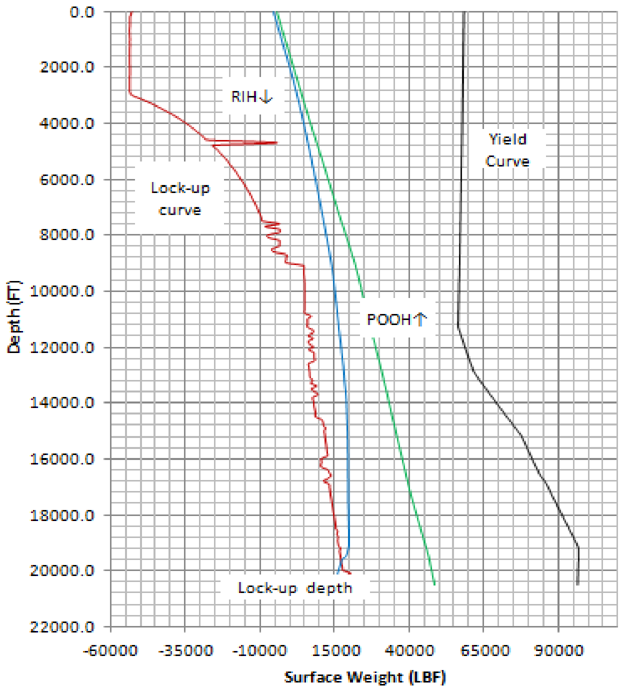
(B)

Figure 2: Theoretical lockup and Predicted surface weight during CT-RIH and CT-POOH considering default values for the coefficients of friction for (A) 8.5-in OH section and (B) 6-in OH section

As before mentioned, chemical friction reducers have been utilized to increase de reach. Table 6 and table 7 summarize the additional reach achieved with a reduction of the coefficient of friction of up to 30%. Based on the simulation outputs, figure 3A and table 6 (run 2) by using friction reducer CT can reach approximately additional 1,300-ft before lockup when the OH section has a diameter of 8.5-in, However, figure 3B and table 7 (run 2) show that when the OH diameter is 6 in, CT can reach approximately additional 1,700-ft. The friction coefficient of 0.30 and 0.24 were respectively considered based on extensive experience running in open hole sections in Saudi Arabia.

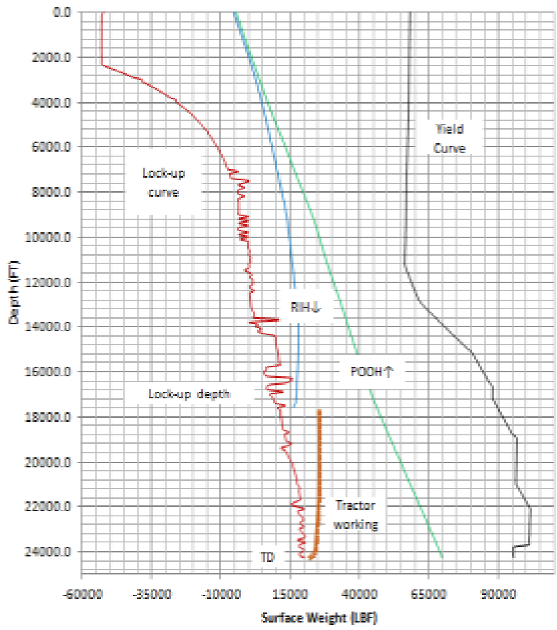


(A)

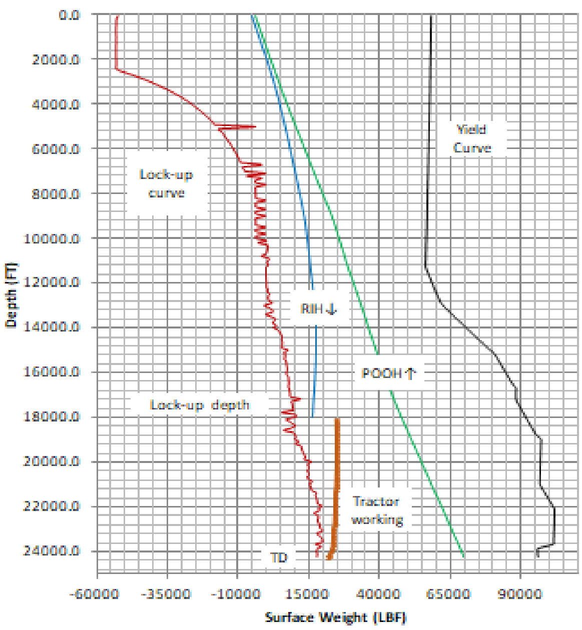


(B)

Figure 3: Theoretical lockup and Predicted surface weight during CT-RIH and CT-POOH considering the use of friction reducer for (A) 8.5- in OH section and (B) 6-in OH section



(A)



(B)

Figure 4: Theoretical lock up and Predicted surface weight during CT-RIH and CT-POOH considering default values for the coefficients of friction and CT-Tractor for (A) 8.5-in OH section and (B) 6-in OH section

In relation to the previous simulations, the Lockup depth was calculated at approximately ±17,900-ft for an 8.5 inches OH section and ±18,800-ft for a 6 inches OH section, in both cases without tractor and without friction reducer and using as reference the friction factors from previous wells [14].

Well intervention simulation indicate the minimum required theoretical force to be applied in the downhole end of the CT string to reach TD for both open hole completion diameters respectively. Figure 4A and Table 6 (run 3) illustrate that CT is able to reach TD (24,260-ft) after applying a minimum concentrated force of 8,700-lbf when the diameter of the OH section is 8.5-in. however as per figure 4B and table 7 (run 3) when the OH section diameter is 6-in, the minimum required tractoring force to pull CT to reach TD is 7,250-lbf.

As can be seen, decreasing the radial clearance (reduce the hole inside diameter, increase the outside diameter of the CT), will increase the horizontal length that CT could achieve due to the reduced amplitude of the CT helix, because CT string has less area to deform inside the hole, in this essay, reducing the ID for the entire OH section significantly increased the horizontal length that can be achieved and the minimum required tractoring force to be applied in the downhole end of CT to reach the same depth is less, this is a favourable condition for the operation of the tractor.

With no friction reducer and using a tractor, CT can reach TD, however in this essay, a fourth run was simulated. Table 6 and table 7 indicate that a reduction in the coefficients of friction will reduce the operational requirement of the tractor, minimizing the utilization time and minimizing the required fracturing force in the downhole end of the CT string to reach TD.

On the other hand, the theoretical force required to reach TD has to be compared to the force available from the tractor including safety margins. [12]

The yield curve shows the maximum stress that can be applied to the CT at the simulation conditions, the Trip-out curve has to be less than the yield curve to guarantee that an overweight it is not applied on the CT when pulling out of well, an overweight which could generate integrity problems in the CT.

As per the results of the simulation, it is concluded that CT can reach the depth of interest without risk.

In all cases, the calculated stress factor is less than 0.8, as per literature review the CT stress factor during trip-in and trip-out have to be less than 0.8 to guarantee that the applied force on the CT-string will not result in deformation, or strain. [7]

VII. CONCLUSIONS

Based on the results of the force simulations, four major conclusions are drawn:

- The best scenario is to use friction reducer, By using friction reducer the CT can reach approximately additional 1,000-ft in average before lockup, which reduces the operational requirement of the tractor (minimize the utilization time and the required force of the tractor), hence the operation is faster and more efficient, If friction reducer is used, the required force from the tractor is reduced around 55% in average.
- Additionally, an improvement on the reach is observed with the 6-in OH section option, if the open hole section is 6-in the CT reach is increased by additional 1,000-ft before lockup in average, because the string has less area to deform inside the hole. This is a favourable condition for the operation of the tractor.

Based on the analysis and the previous conclusions the engineering recommendation is to use friction reducers in the operations, and if it is feasible to complete the well with 6-in OH horizontal section, as this improves the efficiency of the CT intervention. It is important to note that the simulations were done with tentative directional surveys, as the wells are drilled and the final surveys are available, the simulations must be adjusted with the real directional surveys.

VIII. NOMENCLATURE

Bbl – Barrels
BHA – Bottom hole assembly
BHFP – Bottom hole flowing pressure
BHT – Bottom hole temperature
bpm – Barrels per minute
CoF – Coefficients of friction
CT – Coiled Tubing
ERW – Extended reach well
ft – Feet
ID – Inside Diameter
Lb – Pounds
Lbf – Pound force
m – meter
MD – Measured depth
OD – Outside Diameter
OH – Open hole
POOH – Pull out of hole (trip out)
ppg – Pounds per gallon
psi – Pound per square inch
RCS – Repeating Circulation Sub
RIH – Run in hole (Trip in)
RSV – Relief valve sub
TD – Total depth
TVD – True vertical depth
UOM – unit of measurement
USG – U.S. Gallons
WHP – Well head pressure
YS – Yield Strength

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