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Computer-Assisted in Coiled Tubing Perforation Limitations: A Case Study from MA-X Gas Well

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Abstract. This paper seeks to determine the optimum operating conditions for deploying casing perforation guns based on CT to target depths in gas well MA-X by utilising Orpheus Model in CERBERUS. Orpheus assisted to solve the complicated scenarios and complex analysis involves mathematical modelling which is necessitates for computer processing powers. This study investigated four different Coiled Tubing (CT) intervention operational variables namely borehole assembly, CT grade outer diameter (OD), well fluid type and fractional reducer application included examined two scenarios which are running tools in (RIH) and pulling out from borehole (POOH). Only CT workstring with outer diameter between 1-1/4 inch and 2-7/8 inch is considered due to the wellbore completion minimum restriction. Constrained by economic and logistical reasons, only fresh water, 2% KCl, 15% HCl, sea water and diesel will be considered for the well bore fluid. Fractional reducer effects was simulated and analysed. Based on simulation results, the CT outer diameter 1-3/4 inch workstring optimized operation, the CT grade is QT1000 increased mechanical properties. A suitable well fluid is sea water with application of friction reducer improve CT perforation performances to achieve maximum target depth.

1. Introduction

The Ma-X gas field with water depth 818 m discovered in Malampaya-Camago area are known as deep-water gas-condensate reservoir, located offshore northwest Palawan, Philippines and geologically part of Palawan-Sabah Trough [1- 3]. The well faced several challenges such as small footprint, small time window, cost, live well intervention and deviated well about 49.1° [4]. The challenge in well intervention is flowing immediately post perforation is essential in aiding cleanout of impact after debris generated and reach into desired target depth [5]. These limitations can be addressed through the usage of a CT simulator or by experience and trial error especially in stage of workover, CT perforation operation and wireline as shown in Table 1. The challenge is to optimize the CT approach in order to achieve the main goal of minimum CT runs. Currently in CT operation, there are three individual commercial software are renown for generating excellent simulation outputs namely CERBERUS by National Oil Varco (NOV), COILCade by Schlumberger and CIRCA by Baker Hughes.

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Table 1. Perforation method and considerations in CT operations [6,7].

Perforation method	Advantages	Limitations
CT	• Live well intervention • Fast mobilization and rig-up • Small footprint • Ability to circulate • Minimized tripping time • Minimal crew prerequisite	• Largest workstring available off shelve 2-7/8 inch • Unable to rotate workstring • Unable to reach target depth

The CERBERUS simulation offers assistance in a realistic means of accurately gauging downhole CT operations. The simulated scenarios will be optimized and refined finally narrowing down to the final goal of CT runs into the well carrying maximum length of perforation guns. Most important in running tool out and into a well (RIH and POOH) are return back equipment safely to the surface and set foot into target depth inside a well [8]. The CT simulation for perforation analysis in term of force conditions need to follow such as contact fraction, hydrodynamics and buoyancy. In hydrodynamic force condition, it will have affected RIH and POOH [9].

2. Simulation Works

Table 2 shows four variables are selected simulation input to investigate with varying types and dimensions together with purposes. The Orpheus simulation to be set with speed frequency from 0 until 50 ft/min and maximum pump rate is 0.25 bpm (barrel per minute). In addition, the target depth of MA-X well is 12,743 ft, thus simulation ceases to continue when the configuration reaches the depth. Moreover, the calculation RIH and POOH scenarios behind Orpheus in CEREBRUS simulation are based on Equation 1 below.

$$TD_{max} = f\ [W_{od}, X_f, X_g, X_{fr}] \tag{1}$$

Where are TD_{max} is maximum depth achievable, f is functional, W_{od} is CT outer diameter, X_f is fluid type, X_g is workstring grade and X_{fr} is fraction reducer fluid.

Table 2. CT simulation input variables and parameters in MA-X well study.

Variables	Parameters
BHA tool workstring	OD: 3 inch to 3-3/8 inch, Length: perforation interval
CT Material Grade	OD: 1-1/4 inch to 2-7/8 inch,Grade: QT900 and QT1000
Well fluid types	Diesel (Density-7.115 ppg), Fresh Water (Density-8.33 ppg), 2% KCl (Density- 8.453 ppg), Sea water (Density- 8.536 ppg), 15% HCl (Density-8.943 ppg)
Friction Reducers (FR)	Yes, No

3. Result and Discussion

3.1 Scenario 1: RIH

A simulation barrage by using fixed well diagram, CT parameters with varying CT workstring OD for RIH operation and the results presented in Figure 1 and Figure 2 where the green numbers indicate achieve target depth and red numbers show not achieve target depth. The 1-1/4 inch of OD CT workstring with grade QT900 is unable to RIH until target depth, in all specified fluid systems regardless of fractional reducers. For the same workstring with 1-1/4 inch OD with grade QT1000, it is also unable to run target depth for non- fractional reduced fluid system. The 1-1/4 inch of OD CT workstring grade QT1000 is able to RIH until target depth but only for fractional reduced fluid systems of fresh water, 2% KCl, sea water and 15% HCl. The 1-1/2 inch OD of CT workstring with grade QT900 is unable to RIH to target depth, in all specified fluid systems except for 15% HCl fluid system. In addition, the 1-1/2 inch OD of CT workstring with grade QT1000 is able to RIH to target depth and only for fractional reduced fluid systems of fresh water, 2%KCl, sea water and 15% HCl. For 2 inch, 2-1/8 inch, 2-3/8 inch and 2-7/8 inch OD of CT workstrings for both grades QT900 and QT1000; all workstring configurations are able to reach target depth for all fluid systems, either with fractional reduced or not. In term of economically in RIH operation, the 1-1/2 inch OD of CT workstring with grade QT1000 and sea water as fractional reducer are more feasible and less time consumption. Based on RIH simulations, it can be suggested that relationship between the CT workstring OD and maximum depth achievable in a well intervention is straight forward and proportionate. Therefore, the bigger the OD of the CT workstring, the maximum depth achievable in the intervention increases as mentioned by Elliot [10] and Satti el al. [11].

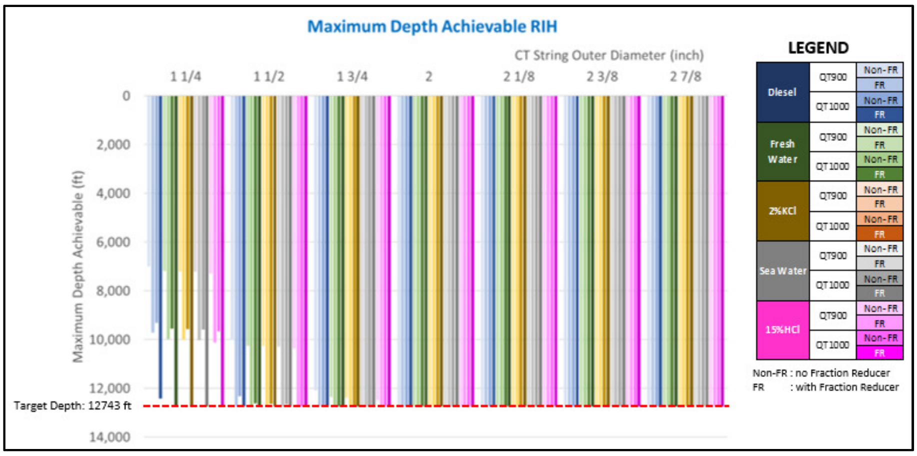
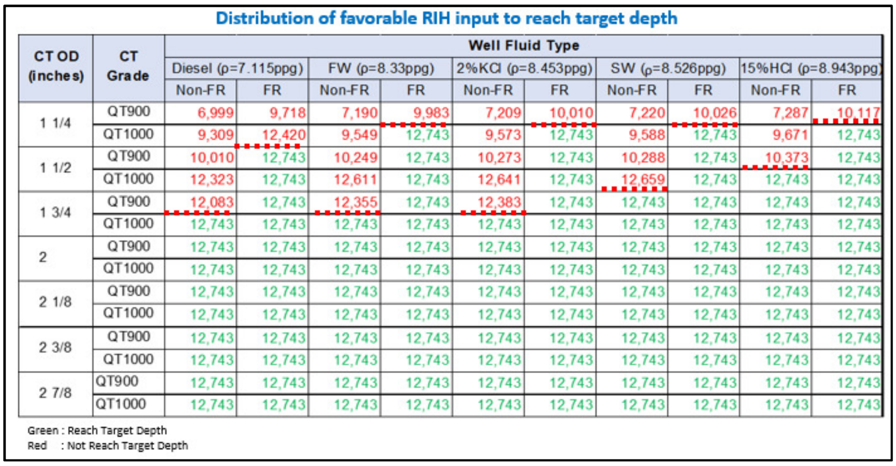


Figure 1. Simulation of RIH with maximum depth achieved against CT workstring OD.



Distribution of favorable RIH input to reach target depth

CT OD (inches)	CT Grade	Well Fluid Type									
		Diesel (ρ=7.115ppg)		FW (ρ=8.33ppg)		2%KCl (ρ=8.453ppg)		SW (ρ=8.526ppg)		15%HCl (ρ=8.943ppg)	
		Non-FR	FR	Non-FR	FR	Non-FR	FR	Non-FR	FR	Non-FR	FR
1 1/4	QT900	6,999	9,718	7,190	9,983	7,209	10,010	7,220	10,026	7,287	10,117
	QT1000	9,309	12,420	9,549	12,743	9,573	12,743	9,588	12,743	9,671	12,743
1 1/2	QT900	10,010	12,743	10,249	12,743	10,273	12,743	10,288	12,743	10,373	12,743
	QT1000	12,323	12,743	12,611	12,743	12,641	12,743	12,659	12,743	12,743	12,743
1 3/4	QT900	12,083	12,743	12,355	12,743	12,383	12,743	12,743	12,743	12,743	12,743
	QT1000	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2	QT900	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 1/8	QT900	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 3/8	QT900	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 7/8	QT900	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743

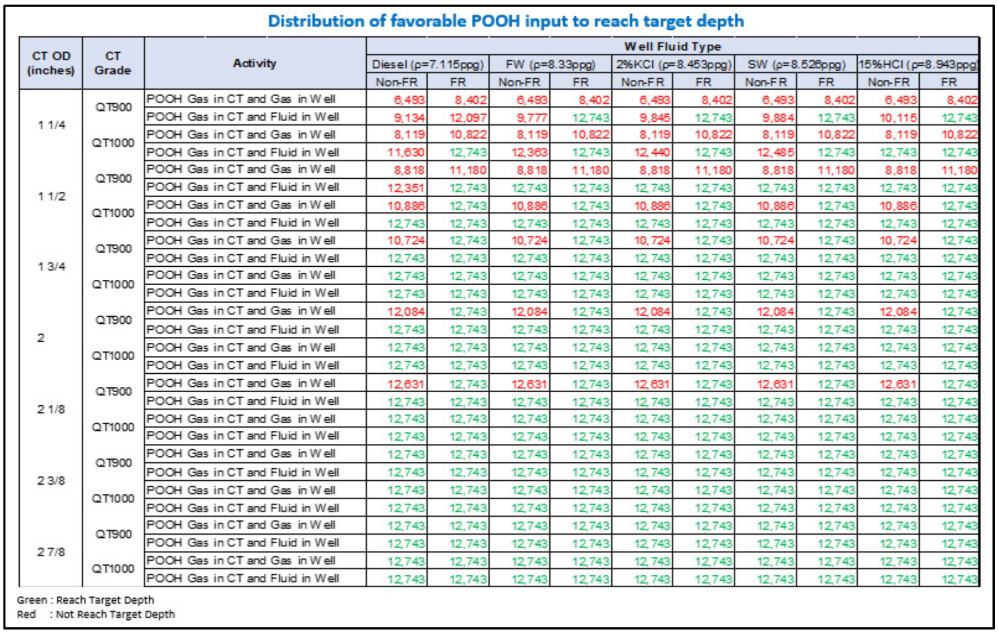
Green : Reach Target Depth
Red : Not Reach Target Depth

Figure 2. Simulation results of RIH parameters.

Apart from that, additional force would be necessary to push the CT workstring into the well fluid to overcome fluid buoyancy. This creates additional burden on the injector head on the surface. It will have to supply additional force (downward direction) to counter the buoyancy force presented by the well fluid were buoyancy force is directly proportional to the fluid density. Thus, the denser the fluid, the harder it is for CT to RIH from desire target depth.

3.2 Scenario 2: POOH

A summarized finding of all the POOH scenarios enabled to arrive inference in Figure 3 which are green numbers indicate achievable depth and red numbers not achieve depth. It can be seen that the 1-1/4 inch, 1-3/4 inch and 1-1/2 inch OD of CT workstring with grade QT900 and QT1000 is unable to POOH from target depth included all fluid systems when fractional reducers is not used. For all workstring configuration of 1-1/4 inch, 1-1/2 inch, 2 inch, 2-1/8 inch, 2-3/8 inch and 2-7/8 inch OD for both QT900 and QT1000; POOH from target depth is favourable for all fractional reduced fluid systems with the exception of the 1-1/4 inch OD of CT workstring with grade QT900, which is unable to POOH of TD with only when drag reduced diesel is present in the well. The 1-3/4 inch, 2 inch and 2-1/8 inch OD of CT workstring grade with QT900 is unable to POOH from target depth for all fluid systems when fractional reducers is not used. It can be proposed that the 1-3/4 inch OD of CT workstring with sea water fluid system without fractional reducers is more favourable and low cost included to counter logistic issues. This result showed that in POOH scenario, the injector head provides a tensile load effectively pulling the workstring out of the completion into the surface. Contact friction now acts in reverse direction as compared to initial RIH. Additionally, workstring hanging weight now acts in the opposite direction of motion inadvertently increasing the stress in the CT workstring as oppose to initially assisting in the RIH operation. Assisting workstring motion are also the bottom hole pressure and flow friction. Pulled into tension loading, the workstring enters a gravity stabilized profile as suggested by Livescu and Craig [12] Guimaraes et al. [13].



Distribution of favorable POOH input to reach target depth

CT OD (inches)	CT Grade	Activity	Well Fluid Type									
			Diesel (ρ=7.115ppg)		FW (ρ=8.33ppg)		2%KCl (ρ=8.453ppg)		SW (ρ=8.526ppg)		15%HCl (ρ=8.943ppg)	
			Non-FR	FR	Non-FR	FR	Non-FR	FR	Non-FR	FR	Non-FR	FR
1 1/4	QT900	POOH Gas in CT and Gas in Well	6,493	8,402	6,493	8,402	6,493	8,402	6,493	8,402	6,493	8,402
		POOH Gas in CT and Fluid in Well	9,134	12,097	9,777	12,743	9,845	12,743	9,884	12,743	10,115	12,743
	QT1000	POOH Gas in CT and Gas in Well	8,119	10,822	8,119	10,822	8,119	10,822	8,119	10,822	8,119	10,822
		POOH Gas in CT and Fluid in Well	11,630	12,743	12,363	12,743	12,440	12,743	12,485	12,743	12,743	12,743
1 1/2	QT900	POOH Gas in CT and Gas in Well	8,818	11,180	8,818	11,180	8,818	11,180	8,818	11,180	8,818	11,180
		POOH Gas in CT and Fluid in Well	12,351	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	10,886	12,743	10,886	12,743	10,886	12,743	10,886	12,743	10,886	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
1 3/4	QT900	POOH Gas in CT and Gas in Well	10,724	12,743	10,724	12,743	10,724	12,743	10,724	12,743	10,724	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2	QT900	POOH Gas in CT and Gas in Well	12,084	12,743	12,084	12,743	12,084	12,743	12,084	12,743	12,084	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 1/8	QT900	POOH Gas in CT and Gas in Well	12,631	12,743	12,631	12,743	12,631	12,743	12,631	12,743	12,631	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 3/8	QT900	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
2 7/8	QT900	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
	QT1000	POOH Gas in CT and Gas in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743
		POOH Gas in CT and Fluid in Well	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743	12,743

Green : Reach Target Depth
Red : Not Reach Target Depth

Figure 3. Simulation results of POOH parameter with gas in CT and fluid in well.

4. Conclusion

A summarized finding of all the RIH & POOH scenarios in gas well MA-X assisted by CERBERUS simulation model for maximum depth achievable with CT workstring OD are following sequence are the 1-1/4 inch, 1-1/2 inch, 1-3/4 inch, 2 inch, 2-1/4 inch 2-3/8 inch and 2-7/8 inch. However, the optimum OD that suitable for perforation project in this study is 1-3/4 inch. The suitable well fluid type in this perforation project is sea water because economical, logistical friendly and easily procured and requiring no storage tanks to reduce small footprint issues. Application of fraction reduced fluid will lower friction hence assist in RIH and POOH operations.

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