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Concentric Coiled Tubing, Proven Sand Cleanout Technology for Sub-Hydrostatic Wells in Caspian Sea

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Abstract

Influx of sand production is one of the major issues faced in oil and gas wells on the Caspian region. Although there are multiple technologies to address this issue, the application of these technologies require the well to be cleaned before proceeding with any kind of remedial application. Concentric Coiled Tubing (CCT) sand vacuuming technology has brought a massive advantage for efficiently cleaning the wellbore of sub-hydrostatic wells in Caspian Sea.

CCT system is the Coiled tubing string inside of Coiled tubing string which essentially provides a smaller second annular return route for the wellbore solids while simultaneously boosting the return pressure and allowing to clean the sand where the bottomhole pressure (BHP) is low and not enough to support the circulation of fluids used for the cleanout. Cleanout fluid is pumped through the inner string to power the downhole jet pump comprised in CCT bottomhole assembly (BHA) which creates a drawdown that vacuums the solids and circulates the solids back to surface via the CCT annulus.

The solid performance of the CCT system has an established track record worldwide and application of this sand cleanout technology brought a solution for recovering many wells with low BHP and has been successfully implemented since 2013, providing a method for cleaning out tons of accumulated sand particles from challenging wells in Caspian Region. With the complex system being used for cleaning out sand and also surface handling of the solids in the return flow from the wellbore, CCT sand vacuuming technology has proven to be effectively functioning in all cases that it was selected for so far.

This Paper reviews the design and mechanism of the CCT sand/well vacuuming system as well as the results of several well intervention cases with its successful execution and lessons learned in Caspian region.

Introduction

Sand production is one of the most common problems faced by operator companies producing hydrocarbons from sandstone reservoirs. Although different types of sand control methods can provide some type of barrier for sand inflow from reservoir, still sand migration and consolidation in wellbore is observed.

The results of sand production are very costly and can be catastrophic. Usually sand production results in the reduction of oil production rates. But sand production can result in erosion and damage to downhole wellbore components and surface equipment, provoking a potential loss of containment in some more severe cases, and force the operators to undertake expensive, time consuming repairs or replacement of wells and production facilities.

Furthermore, sand settling in well can slowly cover the pay zones and plug the sections of production which also requires remedial interventions workover for cleaning the formation fines consolidated in wellbore.

Several different types of solutions were developed throughout the decades for removing the sand settled in wellbore in order to be able to further produce from the wells with sand production problem. And most of those methods involve pumping at high rates so that fluid circulation back to surface could be achieved and sand particles could be lifted and handled at surface. Conventional Coiled Tubing (CT) is also considered one of those approaches which can successfully cleanout the well from series categories of fills with different types of specific bottomhole assemblies (BHA), but requires high pump rates or special fluids with good carrying capacity. Either way with high pump rates and special fluids such conventional sand cleanout techniques create excessive downhole pressure against the formation and can result in lost circulation returns at low formation pressure reservoirs which makes fill removal impossible as well as creating potential to damage the formation.

The Caspian Sea region is one of the oldest oil-producing areas in the world and is a progressively significant source of global energy production. Many of the oil and gas reservoirs in Caspian Sea area have low reservoir pressure and operating companies often face the sand production problem despite of the sand control techniques they have applied. The requirement of cleaning out the consolidated sand particles from low bottomhole pressure (BHP) wells in the field created a demand for exploring the Concentric Coiled Tubing (CCT) technology.

The evolution of the CCT technology has brought a unique approach for the solution of this common problem. The sand/well vacuuming technique provided by CCT has been technologically advanced and proven by many filed operations worldwide to clean out wells with low BHP.

Concentric Coiled Tubing Technology

CCT vacuum technology was developed in the mid 1990s in Canada and since then it has been developed and spread worldwide as it provides a simple and very effective solution for such serious problem as sand cleanout from heavy-oil, low reservoir pressure, deviated wells where conventional methods are inefficient.

In general, CCT sand cleanout system consists of two main components working together, which are CCT string and the sand/well vacuuming BHA.

String of CCT is a quite simple concept that consists of a two different sizes of CT pipes inside one another. The fluid selected for the treatment of sand cleanout is pumped through the inner CT pipe with smaller outer diameter (OD) and the vacuumed treatment fluid mixed with wellbore fluid and solids from well flows to surface through the annular space between inner and outer pipes of CCT string.

Figure 1 demonstrates the flow path of the CCT system when vacuuming from the wellbore is performed. CCT string is designed in such manner that the annulus flow velocity is high and the transport of the cleaned solids is not an issue even when the pumped fluid is only water.

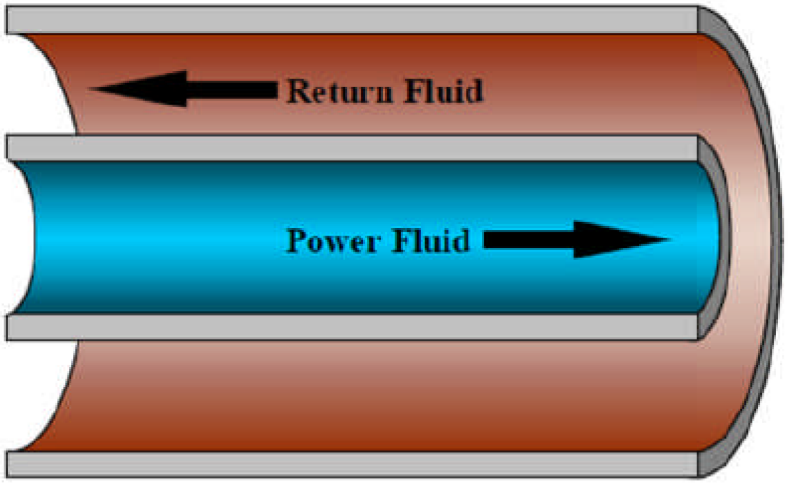

Figure 1—CCT flow path when vacuuming.

For providing continuous fluid circulation on both directions of the flow through the system CCT working reel need to be equipped with a double rotating joints as shown below on Figure 2. Power fluid is pumped downhole through the rotating joint "A" and the return fluids are directed to surface handling units through the rotating joint "B"(Figure 2).

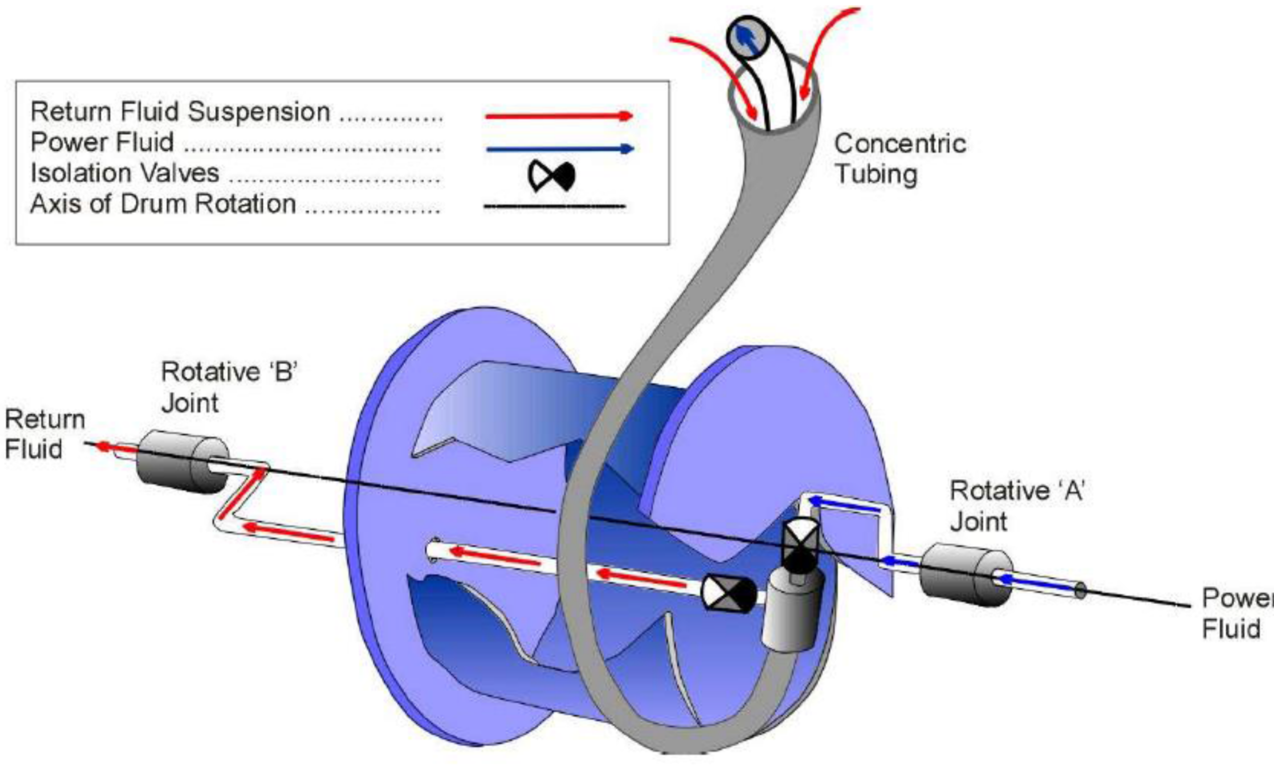

Figure 2—CCT Working Reel

Generally speaking, the vacuuming BHA of CCT technology is a modified downhole jet pump consisting of a high pressure nozzle, an intake port, a throat and a diffuser as described below in Figure 3.

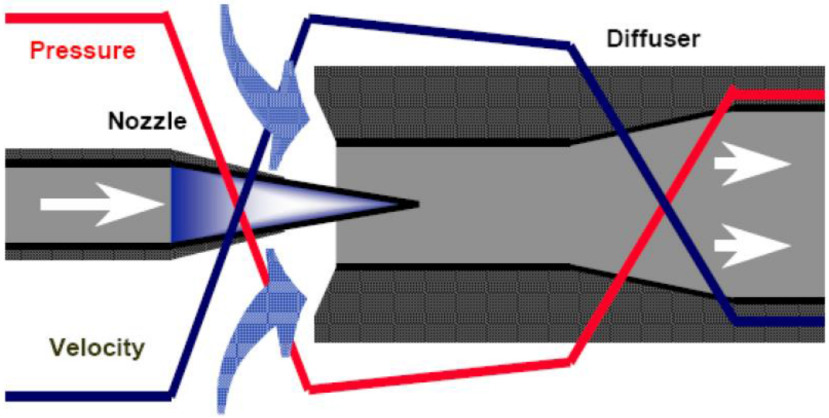

Figure 3—Jet pump principle.

As stated before the chosen treatment fluid which is referred to as power fluid is circulated down the inner CCT string and then passes through the nozzle and enters the throat at high velocity and low pressure which creates a localized suction that draws entrained solids and wellbore fluids into the throat and then into the diffuser, at which point the velocity of the fluid gradually decreases and the pressure builds up. This re-gained return pressure is high enough to lift the mixed fluids and solids back to surface, overcoming friction losses, hydrostatic pressure and surface back pressure.

The CCT vacuuming tool can be operated in three modes and it is designed in a way that it could be remotely switched back and forth by pressure cycling as many times as required during cleanout operation.

Those three operating modes of CCT san vacuuming tool are solids removal, wellbore fluid removal and jetting mode.

In the solids removal mode some portion of the power fluid pumped is utilized for powering the jet pump of the CCT BHA, and the rest of the fluid is directed to the downhole and reverse facing swirl jets with the intention of fluidizing the sand so that it could be vacuumed through the screens of intake port. This mode is illustrated in the Figure 4.

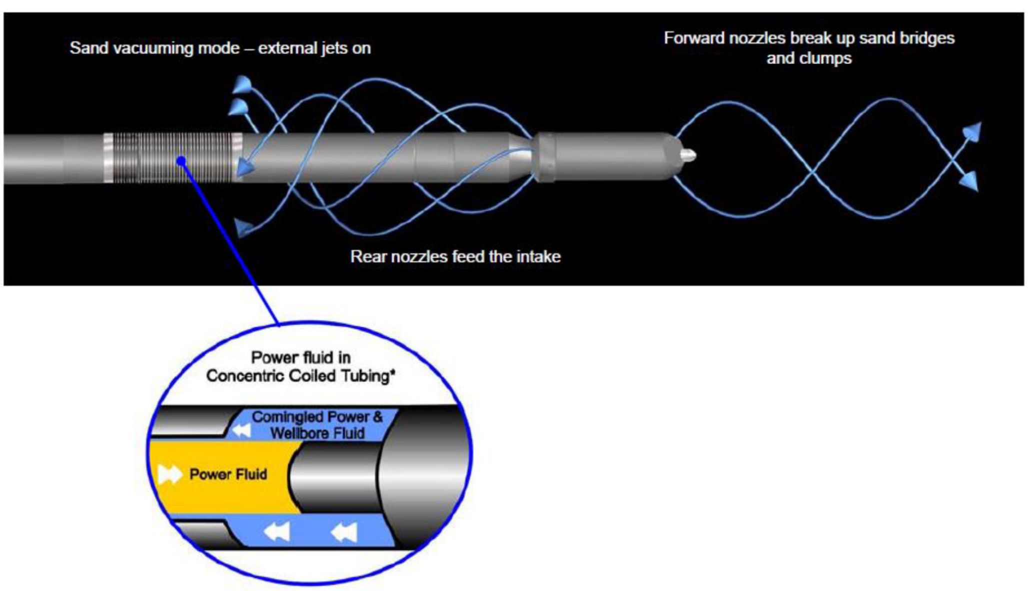

Figure 4—Standard Sand/Well vacuuming BHA shown in sand vacuuming mode.

When the tool is switched to the wellbore fluid removal mode the external swirl jets are shut off and all the power fluid is directed inside of the vacuuming tool. In this case the suction capacity of the tool increases which consequently results in a higher net volume of fluid removed from the wellbore.

The third mode that the tool for CCT vacuuming technology has is jetting mode, in which all the power fluid pumped into the inner string is directed to the forward jetting nozzles, with the purpose of breaking the compacted of hard fill in well in case if encountered during cleanout. Once the solids bridge in well is broken the tool needs to be switched to the solids removal mode in order to remove the broken fluid from the well.

In addition to all the benefits presented by CCT sand vacuuming technology it is possible to include a memory gauge tool in the BHA. The usage of memory gauge makes it possible to record the pressure and the temperature while the cleanout operation is performed and save the job data to the memory chip. Once the BHA is back to surface the data from the memory is used for evaluating the pressure and the temperature while the cleanout was performed. As a matter of fact this data can be used to perform some quick build up tests and analyze the productivity along the entire horizontal section.

CCT vacuuming technology application in Caspian region

One of the main challenges the operating companies face on this field is sand production, despite of sand control methods applied to the wells. So that the reservoirs are sub-hydrostatic the cleanout of the accumulated formation fines in wellbore is also challenging. Although Coiled Tubing was utilized for sand cleanouts the conventional methods were either inefficient or not cost effective. For instance conventional brine circulation cleanout with CT created high BHP and required high volume of fluids, and once the sand bridge was broken and communication with reservoir was established the well was on losses which can create possible reservoir damage as well as sand control screen damage. One way to avoid this is to use Base oil as a cleanout fluid in order to evade creating high BHP and having fluid losses to formation, but this option was too expensive considering the volumes of treatment fluid required to efficiently clean the wells. Another option to avoid large overbalance would be using nitrified treatment fluid but it 's also not profitable as very large quantities of Nitrogen would be required to perform such operation and considering the poor Nitrogen logistics in location and also due to losing hydrostatic advantage when utilizing Nitrogen the cleanout wiper trips back to surface cannot be accomplished.

The feasibility studies done for evaluating the application of CCT technology on wells in Caspian Sea showed a really good results.

Initially outer CCT string with 2 3/8" OD and inner CCT string with 1 ¼" OD was selected for first solids vacuuming cleanout operations, but subsequently CCT strings with smaller OD of 2"×1" were evaluated to be more suitable in order to reduce the surface are of contact between outer CCT string and the production tubing. With this option reducing the drag force of contact would avoid damaging the completion internal coating. Although utilization of smaller OD CCT strings made logistics easier still due to crane lifting capacity limitation on some platforms it was challenging to place the CCT reel at the required spot where the string was supposed to be positioned closer to the center of the pipe deck. For such cases CT reel skidding system is used, so that the CCT string is placed on the spot where the platform crane limitations allow and then using the skidding system it was moved to the final spot for the planned operations.

Feasibility of Application

The main differentiator to a conventional CT job is the use of the concentric string. Once the completion design of the well is evaluated, then the outer string size can be selected based on BHP, well depth and trajectory. Depending on production type, the material grade required for the CT can be identified. This will affect the collapse limitations and the tubing force analysis (TFA).

The inner CT string must be designed to be able to pull its own weight, for the scenario where it might need to be fished out from the outer string. The inner string represents approximately 30% of the weight of the CCT string. This excess weight is also considered on TFA when simulating the maximum depth achievable and the pulling out of the hole (POH) weight expected, utilizing a simulation software. Over pull margins are also taken into account in simulation stage, in order to verify that both CT strings can be pulled out from the well in any given scenario.

Reference the Pipe and Instrumentation Drawing (P&ID) for the detailed equipment and flow path, Figure 5.

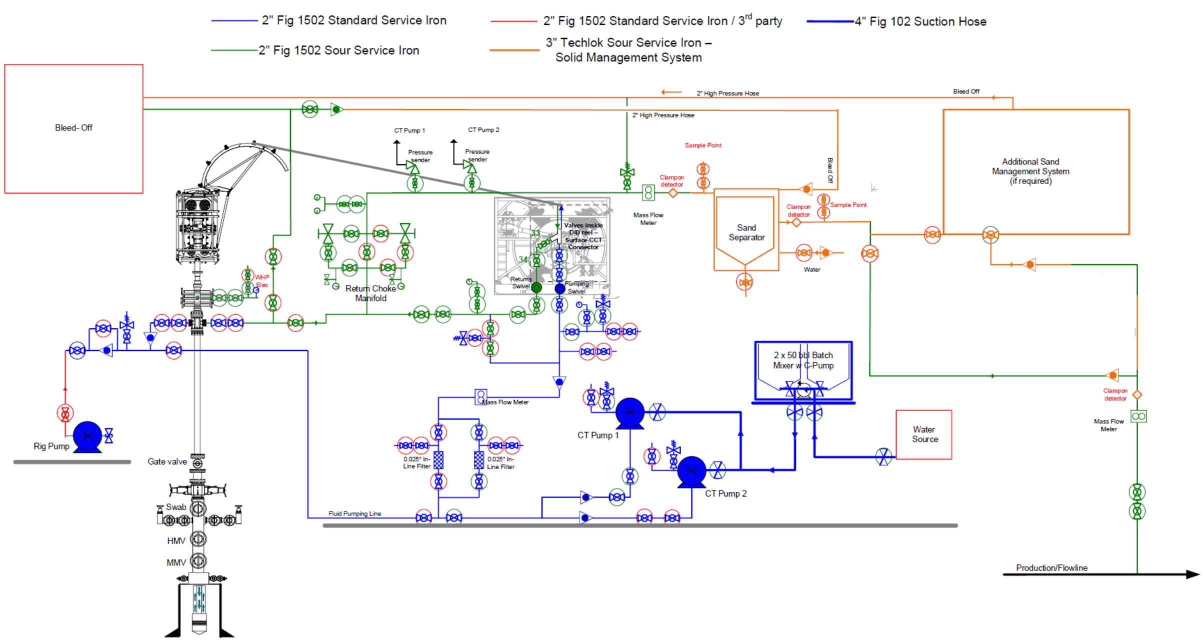

Figure 5—Reference P&ID

Returned Fluid: Returned fluid consists of seawater or 4% KCl brine treated with friction reducer, oxygen scavenger and biocide. A small amount of gas and oil is expected with the returns. Expected sand concentration is 1-2% by volume in the returned fluid.

Flowpath: Fluid and sand will be returned to surface via the CCT annulus. It will flow from the CCT surface connector to a solids management system via 2" 1502 chicksan. The fluid filtered from sand will flow from the solids management system to the production flowline and into a separator at estimated 350 psi. Fluids ultimately flow into the production system and into a pipeline

Flowrate: Accurate return fluid flow rate measurement is critical for determining:

a. Effectiveness of the jet pump (CCT BHA)
b. Concentration of solids in the CCT annulus
c. Rate of penetration (limited by solids concentration in the annulus)

The expected pump rate is 0.4bpm - 0.7 bpm, anywhere from 5,000 psi to 9,000 psi. The return flow rate is estimated to 0.6 bpm. The difference between pump and return rate (~0.1 bpm) will consist of wellbore fluid (oil, gas or water).

Pump rate will be measured with a 1" turbine flowmeter upstream of the inner coiled tubing string. The return flow rate will be measured by a 1" turbine flowmeter and a mass flow meter. If gas is present in the returns, both of these meters will be ineffective in measuring flow rate.

If gas is continuously present in the fluid, the returns can be temporarily diverted to a 1440 psi surge tank, located downstream of the solids management system. The surge tank has a magnetic level to measure fluid level vs. time. Surface pressure will be maintained with a manual choke, gas is vented to the mud-gas separator on the rig. Fluid will be contained in the surge tank and pumped into drilling cuttings boxes (DCB's) for disposal after the job.

The surge tank serves as an alternate flow path in case of a production facility shutdown. It provides enough fluid capacity to displace the sandy fluid out of the CCT annulus (49 bbls), thereby preventing a sand bridge from forming.

Sand: Sand will be removed from the flow path at the solids management system and sent to the Cuttings Re-Injection (CRI) well for disposal.

The solids management system consist of de-sander and filtration unit. De-sander unit used to separate sand particles up to 20 microns and fluid by accumulating sand in the tank that must be flushed after sand has accumulated. All the particles less than 20 microns but more than 5 microns will be collected in the filtration unit, which located on the downstream of de-sander unit. There are several clamp on detectors installed on the return line starting from the upstream of de-sander unit and following until the downstream of filtration unit, which helps to measure the solids volume by recording noise that solids create every time when reached surface. De-sander and filtration unit being flushed several times during each run based on solids volume. The water used for flushing can be from the platform sea water or potable water utility. The sand and flush water are routed to the discharge of the rig's mud cuttings shakers. This cuttings trough, is open to the atmosphere. From the trough, the sand and fluid will be sent to the Cuttings Re-injection well for disposal, the same way any other drill cuttings are disposed of. Before flushing the de-sander unit measurements of the tank being recorded, as de-sander unit has load cells, which helps to control amount of sand being recovered from the well.

Sampling: Accurate sand concentration measurements are required to control the rate of penetration, which is main factor for successful cleanout operation. The samples will be taken upstream of the solids management system in order to check initial solid presence and downstream in order to check the efficiency of the system. This will be atmospheric sampling through with double block and bleed 1/2" NPT sampling manifold coming off a data header. Once samples taken, it will be spun out with a centrifuge to measure, solids, oil and water concentration. Later, those results will be checked with solids management system clamp on detector readings, in order to optimize further cleanout by maintaining penetration rate or POH speed.

The study conducted to evaluate sand clean out operations with CCT, started by evaluating each candidate well with lowest pressure gradients around a certain field, based on test data processed and equivalent specific gravity (SG). Simulations were ran with the sand vacuum tool BHA in these wells to estimate SG limits for the cleanout using the CCT strings designed as per completion type information.

Summary of SG limits for the operations based on simulations in field, are described below.

Fluid returns from the well can either be taken to production test separator pressure of approximated 350 psi. An alternative for a lower backpressure, is also 50 psi using the degasser vessel from the solids management system and pumping the returns back to production using multi-phase pumps.

Considerations

Power Fluid: 1.05 SG brine
Back Pressure: 350 psi / 50 psi
Completion Solids Bed: 80%
Rate of Penetration: 0.2 m/min
BHP: as per latest available well test data
Length of 2"×1" string: 5800 m

Conclusions

98% of the wells can be cleaned out using 2"×1" CCT string design.

Wells that are not feasible to be cleaned with 2"×1" string without leaving power fluid in the well due to SG is below 0.59 and this consequently involves very high pumping pressures on surface (>9000 psi). An alternative option, is to leaving some power fluid in the well (not full vacuum at the BHA), then it is likely even these very low pressure wells can be cleaned using 2" × 1" CCT. Experience in this mode has been achieved in wells with BHP gradients lower than 0.5 SG.

Some of the wells that can be cleaned, would require to be cleaned with 2"×1" CCT returning to 50 psi back pressure (using a multiphase pump setup downstream of the degasser tank).

Pressure Control Equipment

As in any other CT job, since the intervention is performed with a live well, the pressure control equipment is the most critical point and due diligence must be done in selecting it.

The identified barriers are the CT stripper, the outer CT string (fluid is pumped downhole through the inner string), pipe rams in blow out preventer (BOP), shear seal rams in upper BOP and the shear seal utilized in lower BOP. If containment is broken in the above-mentioned barriers, the following barriers identified are the master valve and the swab valve in the well intervention block.

The selections of BOP and accumulators were done in compliance with the company's Coiled Tubing Pressure Control Equipment Standards.

The general BOP consideration, following API Recommended Practice 16ST, where the capacity to shear the outer and the inner designed pipe can be verified through calculations detailed.

Hydraulic pressure obtained to shear each pipe added together is compared to the maximum hydraulic working pressure of the manufacturer for each specific equipment. This calculation is a function of the wellhead pressure (WHP), wellbore area, shear area calculated and theoretical shear of the equipment according to the manufacturer specifications. The calculation must be done for different body diameters of each BOP analyzed for the selection.

The BOP's selected have a maximum hydraulic working pressure of 3,000 psi. The highest hydraulic pressure required to shear both coiled tubing strings in the heaviest wall thickness, considering an operating worst-case scenario, was below the 85% of the BOPs.

After the BOP selection, the accumulator size according to the capacity of required to operate the every ram of the BOP, with 1.5 cycles each. This is calculated by estimating the hydraulic oil required to have minimum operating pressure and to maintain pre-charge pressure.

Pre-Job Engineering Design

Pre-job design starts with evaluating the job scope and gathering as much as possible well data to do proper analysis in order to achieve successful operation. Prior to start modeling the CCT operation, choosing the string and the right configuration of the BHA, as well as selecting the equipment for the job on suggested well the information provided by the operating company must be checked to adapt it as an input in simulation program. All the data related to well as deviation survey, completion components, well pressure temperature details, production details and well condition are entered to the simulation software and calibrated to match the model with real well condition. It is important that the input in simulation software is correctly loaded to get the accurate model of the downhole conditions before designing the job.

Once the proper well condition scenario is obtained the TFA are evaluated to find the appropriate CCT string to be able to safely run in hole (RIH) (Figure 6) and POH the target depth considering recommended limits and any extra forces required for the planned job scope.

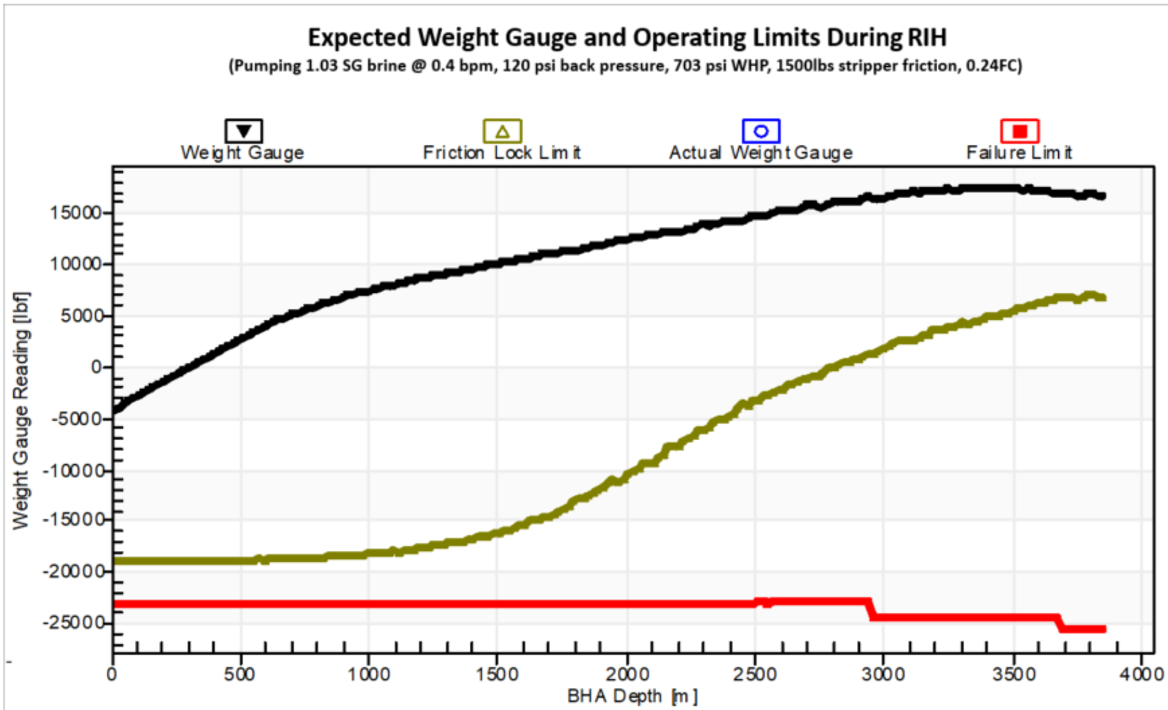

Figure 6—Coiled Tubing Force analysis for RIH

After selecting the CCT string the main step is to design the optimal configuration of the CCT Sand vacuuming BHA to clean all the solids from the planned well. To set up the tool model flow analysis simulation is performed to obtain a flow rate and injection pressure as a function of the cleaning parameters (rate of penetration (ROP), suction rate, return rate, etc.) to work safe and effective. Key components of the BHA are the power nozzle, throat and diffuser so that selected treatment fluid is pumped through the nozzle at high velocities into a throat where suction is created and then into the diffuser, where the velocity of the fluid is reduced and kinetic energy is transformed back to potential energy. Different tool configuration scenarios are simulated to compare the outcomes focusing on several factors such as Workstring injection pressure, CT Gooseneck pressure, pump rate, gain and loss, return rate, tool inlet pressure, diffuser pressure, solids loading and CCT annular velocity.

Table 1—Parameters studied for tool configuration.

BHP (psi)	ECD (sg)	Nozzle #	Throat #	Bypass Orifice (in)	Switch Orifice (in)	Workstring Injection Pressure (psi)	GNP (psi)	Workstring Flow Rate In (bpm)	Main Nozzle Flow (bpm)	Swirl Nozzle Flow (bpm)	Return Swirl Nozzle (bpm)	Total Suction Flow {bpm}	Total Return Flow {bpm}	Gain loss {bpm}	Nozzle Inlet Pressure {psi}	Tool Inlet Pressure {psi}	Throat Pressure {psi}	Diffuser Pressure {psi}	Wellbore Pressure at suction {psi}	Surface Returns Pressure {psi}	Burst Pressure @ BHA {psi}	Solids Loading {lb / gal}	CCT Annulus Velocity {in / sec}

According to field experience workstring injection pressure is usually close to 8,000 psi for 2" × 1" CCT, due to the high true vertical depth (TVD) and the BHP present in numerous wells drilled in Caspian Sea. This pressure is used as a reference taking into account the security factor for the reel rotating joint (rated at 10,000 psi) and the maximum allowable working pressure for the OD of the pipe, when designing the job.

After assessing all the suitable options that meet requirements, most effective one is chosen and CCT Sand vacuuming tool is redressed to the suggested configuration. In some cases suitable tool configuration cannot be found using the suggested fluid for the operation due to high estimated pressures, in that case friction reducers can be considered for reducing the expected pressures in order to be able to achieve successful cleanout. Once it's redressed as per designed configuration the tool is also function tested in the yard to see if the software simulation results match with actual pressures vs. rates.

As any type of BHA components with ball drop activation option is not applicable for the CCT technology, the tool disconnect option is designed to function with shearing the rings with application of pull force at the BHA. Another stage of the modelling is for choosing the proper Shear ring rating for the BHA, utilizing the CT force analysis simulations. Evaluating the TFA with different scenarios gives a chance to choose the optimal Shear ring rating that will enable to apply required force to activate it in an emergency case when the CCT is at the bottom of the well also considering to have an optimal margin before the shear ring rating could be reached during the operation. Once the optimal rating of the Shear pin for BHA is chosen the POH force analysis chart is generated accordingly, Figure 7. During the operation the chart generated using the 70 % of pipe failure limit and shear pin limits is used for reference.

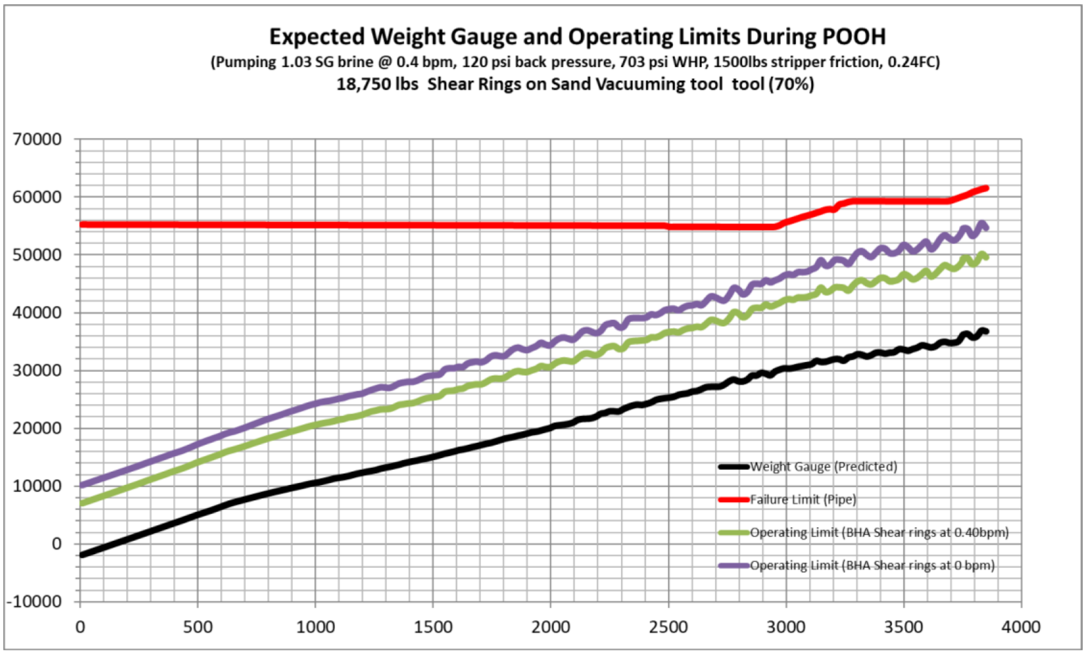

Figure 7—Coiled Tubing Force analysis for POH

The next step for the CCT job design is to evaluate the Maximum allowable differential pressure across the outer CCT string with different pipe ovalities in order to consider the worst case scenario for limiting the WHP to avoid the collapse of the CCT string. The TFA is performed for the 0.5%, 1.5% and 2.5% ovalities of the CCT pipe, Figure 8.

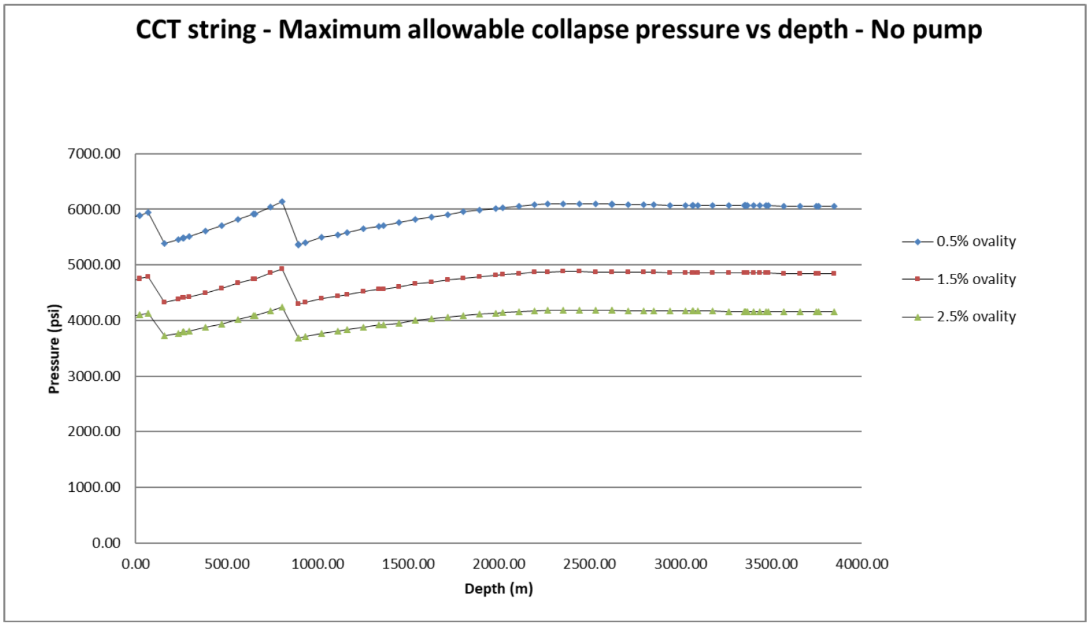

Figure 8—Coiled Tubing Force analysis for Maximum allowable differential presure across the CCT string

Other than force analysis the CT flow analysis is also performed in a simulation software to set the limitations for pumping rates and pressures. So that for the solids cleanout the CCT sand vacuuming tool is used in two modes which are Solids removal mode and Jetting mode, the simulation is evaluated for range of the allowed pump rates for both modes, in order to have a reference of the expected pressures for the pump rates during the operation, Table 2, 3.

Table 2—CCT Tool Jetting Mode Predicted Pump Pressure vs. Pump Rate

Jetting Mode Predicted Pump Pressure vs. Pump Rate w 1.03SG Brine		
Down Jetting 2x0.125", Circulation Point @ 3848 m		
Pump Rate (bpm)	**Pump Pressure (psi)**	**Expected Return Pressure (psi)**
0.3	2881.3	140
0.35	3663.8	140
0.4	4557	140
0.45	5560.7	140
0.5	6674.3	140
0.55	7897.4	140
0.58	8683.7	140

Table 3—CCT Tool Solids removal Mode Predicted Pump Pressure vs. Pump Rate

Sand Vacuuming Mode Predicted Pump Pressure vs. Pump Rate in E-01 w 1.03SG Brine			
Pump rate (bpm)	Pump Pressure (psi)	Expected Return Rate (bpm)	Expected Return Pressure (psi)
0.38	6978.1	0.4731	140
0.4	7790.2	0.5134	140
0.42	8546.3	0.5476	140

Riser Stress Analysis

A structural stress analysis was required to assure that the equipment rig up was safe to perform with the selected equipment and the expected working scenario.

A tension table work to prevent excessive bending stresses being placed on the stack below the rotary table. Expansion of the stack should be monitored if the case of heats up considerably during operations (flowing the well). Pressures need to be monitored in the load cylinders to look out for additional axial load in the stack. A model of various loading and stress conditions on the proposed intervention stack were assessed and determined if equipment stress levels exceed the target working limits established.

This type of analysis and stack design repetition process can be used to optimize the equipment selection and configuration of the intervention stack. Main concerns were yielding of components, buckling occurring on the stack and flange bending limit. So testing would determine if specialized components or materials are required.

A detailed list of every single component in the stack was considered for this analysis, some of these components included dimensions, material and connection types. Weight of equipment and forces applied by it, while performing the intervention, were included in the analysis. Example of the parameters can be seen on Figure 9.

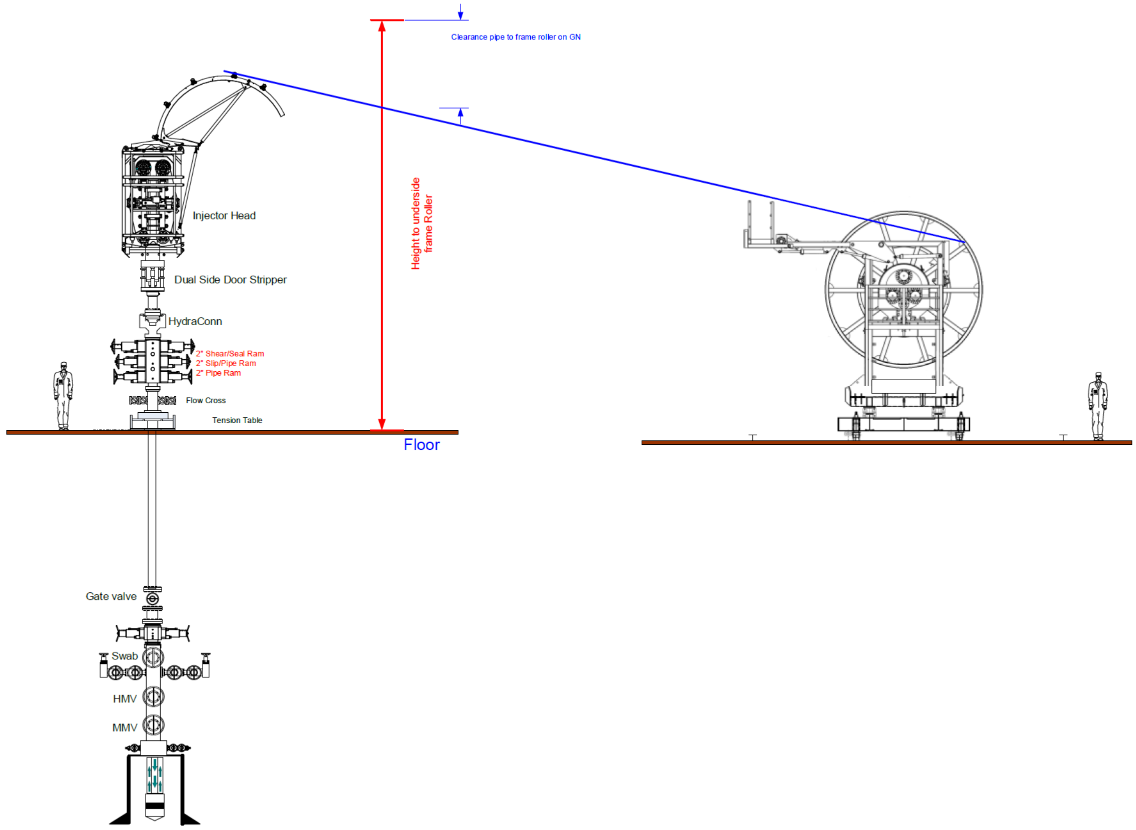

Figure 9—CT Stack type analyzed

The positioning of the equipment, relative to the location of the intervention stack is critical for the stress analysis, therefore, a layout Figure 10 of the dimensions and positioning of the equipment rig up was considered. So X, Y, Z axis were all required for proper study.

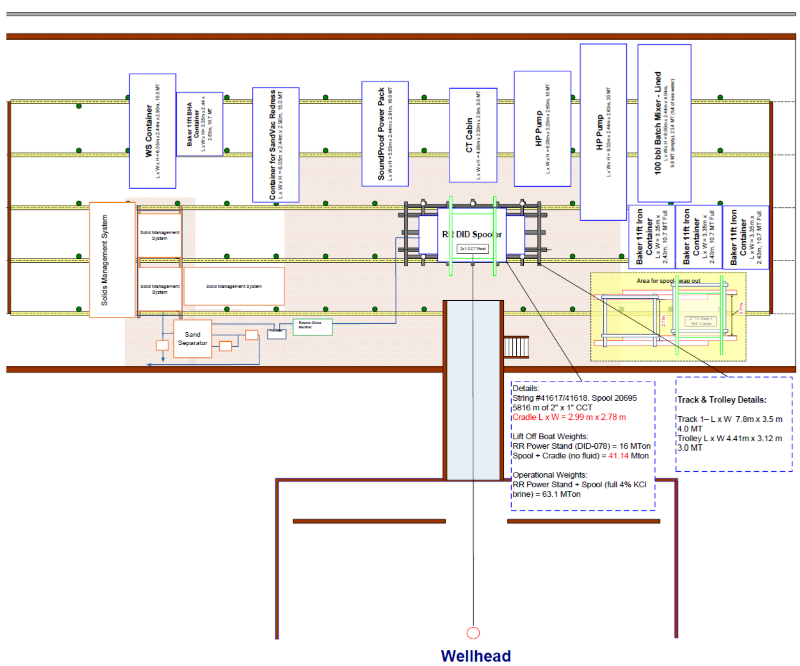

Figure 10—Layout of equipment

The scenario type considered for the intervention are detailed as below:
Typical scenario with CT (near surface):

- Zero CT weight in hole
- 10,000 lbsF tension applied at Tension Table
- 4,000 lbsF line pull from the spooler
- 2,000 psi WHP
- Bending moment applied at gooseneck
- Injector chained back to rig structure on opposite side from spooler

Worst case scenario (near surface):

- Zero CT weight in hole
- 10,000 lbsF tension applied at Tension Table
- 8,500 lbsF line pull from the spooler
- 3,000 psi WHP
- Bending moment applied at gooseneck
- Injector chained back to rig structure on opposite side from spooler

Typical scenario (deep in well):

- 120,000 lbsF CT weight in hole
- 10,000 lbsF tension applied at Tension Table
- 3,000 lbsF line pull from the spooler
- 2,000 psi WHP
- Bending moment applied at gooseneck
- Injector chained back to rig structure on opposite side from spooler

Worst case scenario (deep in well):

- 120,000 lbsF CT weight in hole
- 10,000 lbsF tension applied at Tension Table
- 8,500 lbsF line pull from the spooler
- 3,000 psi WHP
- Bending moment applied at gooseneck
- Injector chained back to rig structure on opposite side from spooler

In summary, the stack designs as modeled during all scenarios showed good results and that working parameters were below the maximum load ratings for the equipment when utilizing the inputs for a typical job, this included application of typical safety factors.

Historic Technology Milestones in Region

There are multiple unconventional cleanout applications with the use of CT, but only the use of CCT has the capability to reach targeted cleanout depths, mostly due to the low BHP's from the wells.

A few cleanout techniques, which could be applicable to a partial number of the low BHP wells, are described below.

Traditionally, the approach to remove sand has been to run the CT to the top of fill, increase the flow rate, and then start penetrating the filled interval. The job can be carried out by continuously low penetration rate into the fill or cleaning 10 to 15m interval and then reciprocate the CT over the last interval. Until the target depth is reached and a bottoms up is performed to displace sand to surface. This requires enough BHP to be able to sustain hydrostatic pressure caused by treatment fluid and sand being displaced up hole.

Wiper Trip Hole Cleaning

For decades numerous studies, extensive testing of solids-transport for the stationary circulation and the wiper trip have been conducted. The effect of ROP, well trajectory, circulation fluid properties, single/multi-phase flow, particle density and size, fluid rheology, wiper trip speed, and specialty tools with different nozzle type on solids-transport have been researched.

Wells with low BHP can be particularly challenging to clean because the use of nitrogen usually results in a necessary reduction in the liquid phase that can be circulated and may result in an overall reduction of the in-situ liquid phase velocity.

Overall, proper selection of fluid type and rates, CT RIH and POH speeds is crucial to ensure a successful cleanout with the wiper trip cleaning process. Proper pre-job planning and engineering is achieved by using modelling software developed specifically for this application, Figure 11.

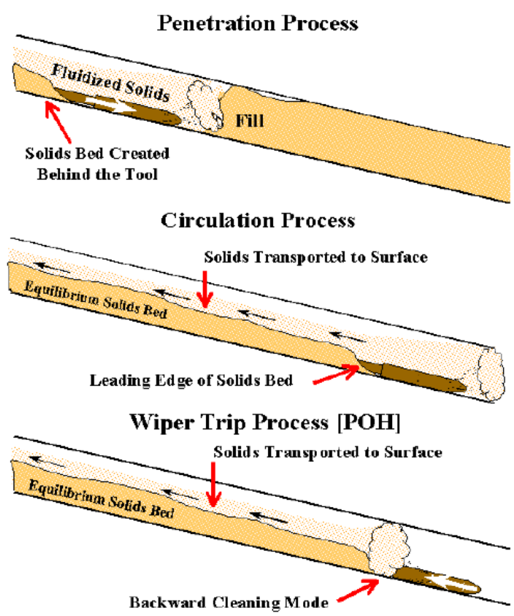

Figure 11—Typical stages of debri-cleanout with wiper trips

Reverse Circulation Cleaning

In some cases the forward circulation mode cannot effectively clean the fill out of the wellbore because the size of CT is not suitable to achieve the required circulation rate for circulation/wiper trip methods. Due to the smaller internal flow area of CT it is possible to achieve higher circulation velocities inside the CT and fill can be effectively transported through by reverse circulating up the CT string. Although this is potential cleanout option, there are some risks that come with it. One is the collapsing of CT string, which will lead to an uncontrolled release of fluids from reservoir at surface, situation which is normally controlled by check valves in the forward circulation cleanout (inexistent on reverse circulation). Another risk is the ideal rate of penetration of the CT during cleanout, since it can easily slack off into the fill and plug the nozzles, hence losing returns and end with string full of debris, Figure 12.

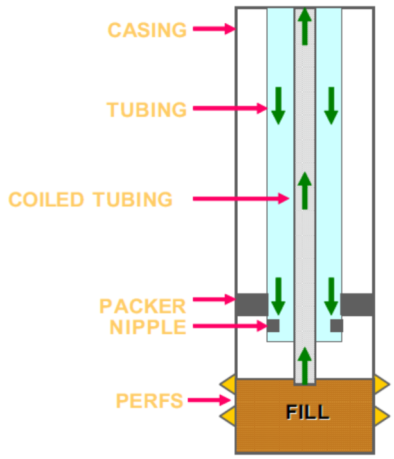

Figure 12—Reverse Circulation

There is very limited jetting action in case an obstruction is encountered, therefore, multiple trips might be required in order to change BHA to be able to break through high compacted fill. It is important that if fluid is easily lost when communication with reservoir exists, that will most probably mean the end of the reverse circulation cleanout, since additional fluid pumped through backside, might not be enough to compensate fluid lost to formation.

Specialized Fluids: Foam and Polymers

Some cases, mostly caused by the completion size and the low pressures from reservoir it is required to use fluids with improved solids suspension capabilities, like polymer systems with nitrogen or foamed fluids. The flow regime, geometric combination of hole/CT and eccentricity, also affect the rheological state of the liquid and have a significant impact on solids cleanout efficiency.

The challenge that rises with this type of fluid, is that when the solid fall and form a bed across the well, it can hardly be re-entrained for a proper transportation to surface. To aid on this, an efficient jetting effect is required to be used.

Due to the complexity of the structure and the corresponding properties, it is very challenging to accurately predict foam flowing behavior in the wellbore. The rheology of the foam is affected by many parameters.

Currently the primary candidates for foamed cleanouts are vertical wells with low BHP's and large diameter completions.

However, the complexity of mixing and handling foams and the additional annular flow friction created by foamed fluids if the completions tubulars are flow restrictive often eliminates it as well cleanout option.

Sand/Junk Bailers

Different types of sand bailers have been developed and used to remove large sand particles, junk and debris from wellbore. Two common types of bailers are the vacuuming type, venturi junk basket, and the mechanical type, as the rotational sand bailer. Sand bailers are not dependent on hole size to work. The materials typically cleaned using this method include falling metal objects, scale, milling material, large debris, and consolidated material. The sand bailer is used to identify the top of fill and evaluate the conditions where other sand cleanout process would be applicable.

The venturi junk basket (Figure 13), works by pumping fluid through the CT string and exits the nozzles in the venturi chamber, at this point a vacuum is created in the venturi chamber. Fluid is sucked from the bottom of the tool and exits back through the venturi tubes.

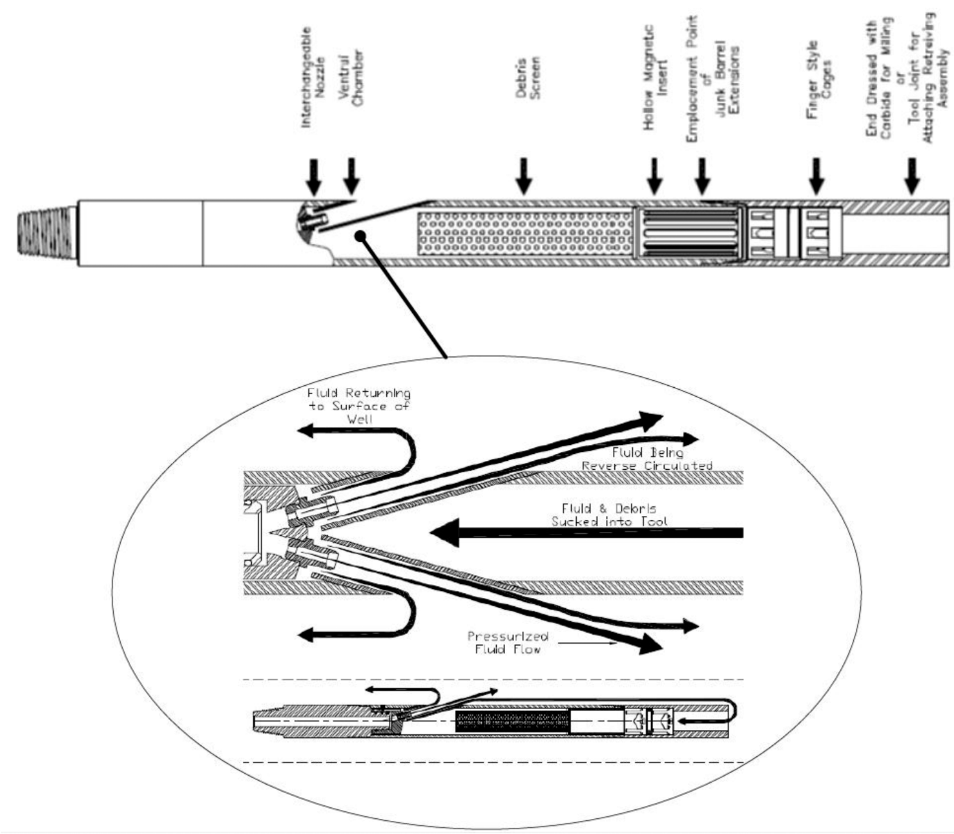

Figure 13—Venturi Junk Basket

The tool is essentially a vacuum cleaner that may be used with liquid, nitrified fluids, or gases. The nozzles in the tool are selected and configured for the planned pump rate of fluid or gas. It is used with a debris filter above the venturi chamber to prevent debris from blocking the venturi tubes. A collecting section/chamber with a finger type trap, collects junk and debris, which is then carried out to surface. The volume of fill collected is limited by the size of the collecting chamber.

Usually, multiple runs have to be made, emptying the basket after each trip. Junk baskets are generally only practical if the volume of fill is relatively small.

Before CCT application been implemented in Caspian Sea, historically most of the wells were cleaned with conventional CT cleanout methods for both "live" and "dead" wells. Both approaches had significant challenges, such as high risk of getting stuck with CT once sand bridge is broken in "dead" wells or flowing even more sand in "live" wells. Sand that's present in formation tending to pack off due to fine particle sizes which creates additional challenges for cleanouts (Figure 14).

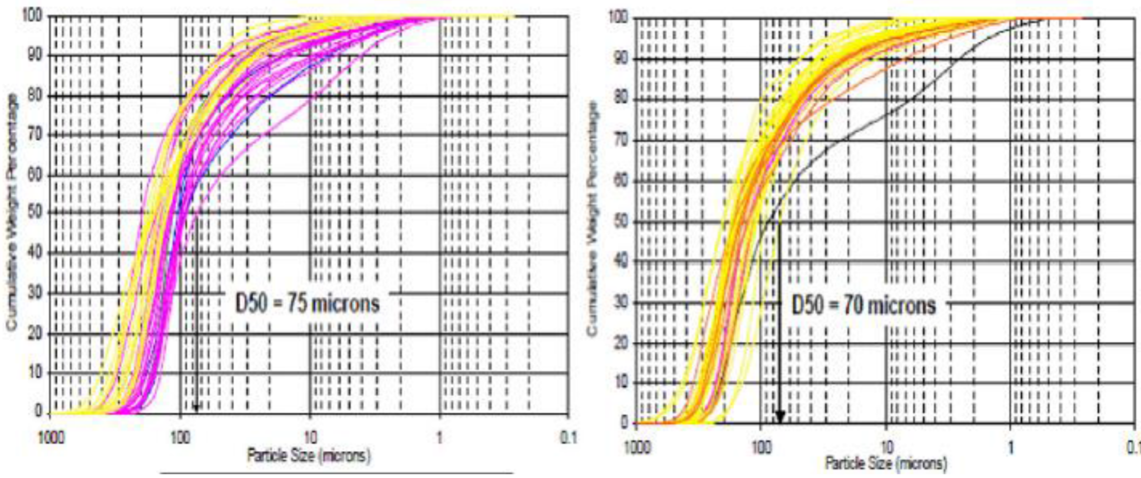

Figure 14—Example of sand particles sizes observed in Caspian Sea

Reducing amount of runs and time spent for cleanouts the CCT sand vacuuming technology makes cleanout operations possible in wells or intervention campaigns where conventional methods or two-phased fluids are not efficient.

The best cleanout method recommended for injector wells is CCT application which allows to clean the entire injection interval including rat-hole. This has a big advantage over conventional methods of cleanout where the risk of losing circulation is reduced to minimum, as well as introducing additional solids into the formation

On the Table 4 shown below is a selection of wells that were cleaned by using CCT Technology in the Caspian region.

Table 4—Summary of CCT Cleanouts performed in Caspian Sea.

Well	BHP, psi /TVD, m	Production Tubing size, in	Max Deviation angle, deg./ MD, m	Distance cleaned, m	Amount of sand cleaned, kg
Well 1	3300 / 2800	5.5	75 / 4300	210	300
Well 2	3200 / 2900	5.5	80 / 4200	980	1600
Well 3	3700/ 2900	5.5	76/ 4400	1260	2400
Well 4	3500 / 2900	5.5	77 / 3700	1500	5000
Well 5	2800 / 2600	5.5	87 / 3800	1000	5200
Well 6	3800 / 3100	5.5	63 / 1600	150	500
Well 7	3100 / 2500	5.5	72/ 4100	100	200
Well 8	3300 / 2600	5.5	80 / 3800	400	4400

To summarize let's look at some information from the most successful CCT Cleanout operations performed in Caspian region.

Well 3 (Figure 15): The oil producer well with 5.5" open hole gravel pack (OHGP) completion was experiencing severe slugging since it was first put online. This is due to a combination of large tubing diameter, low gas oil ratio, low reservoir pressure and low production index. Despite slugging, the well was able to flow naturally for three years, until when it suddenly stopped flowing due to massive sand production. The BHP built up as usual, but the WHP remained low. Attempts to start-up the well were unsuccessful and the suspected reason for this was assumed to be either sand control failure leading to a sand bridge above the downhole gauge or a sub-surface safety valve (SSSV) failure. Diagnostics were performed in SSSV was found to be fully functional. Drift tagged hold up depth (HUD) at 3240m (2250m above the top of screens). Second drift after the bullheading 30 bbls of base oil, HUD tag was observed at 3300 m and a sand bridge was confirmed.

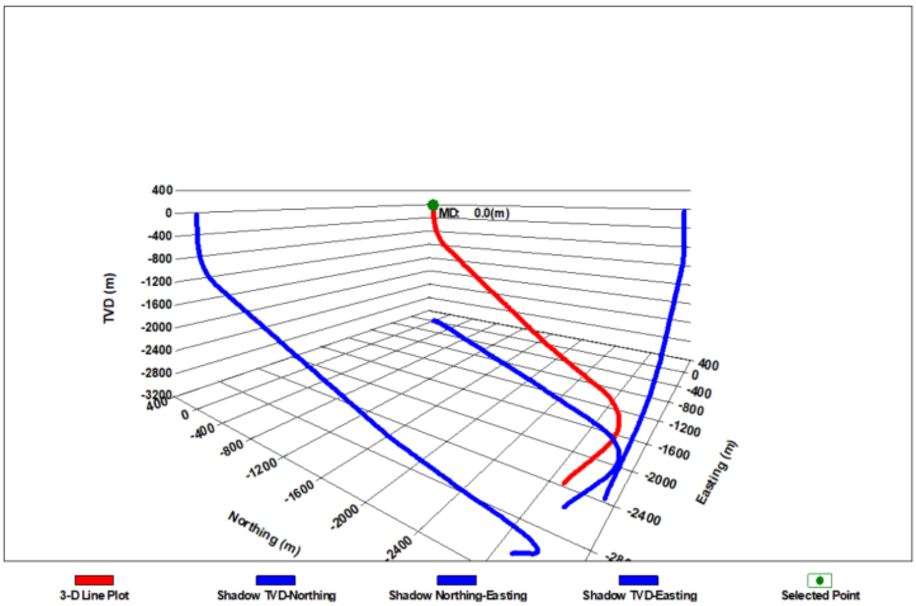

Figure 15—3D Plot of the Well 3

The aim of intervention on Well 3 included performing CCT cleanout to 4500 m in order for the Wireline to gain access to set the isolation plug and then de-complete the well for sidetracking. The planned CCT sand cleanout operation in this well was successful in achieving the objectives set out for the solids removal. CCT reached the 4500 m depth with 4 RIH attempts. 2400 kg of sand was recovered from the 1260 m distance that was cleaned in Well 3.

Well 4 (Figure 16): This well is an oil producer with OHGP, five years after the well was drilled and completed it stopped flowing and restart attempts failed to kick off the well. Scope of intervention operation decided for this well was to perform CCT sand cleanout to 4200 m in order to gain an access for execution of diagnostic log to survey sand screen condition and attempt to determine the potential source of sand production to set plug and isolate the damaged screen section.

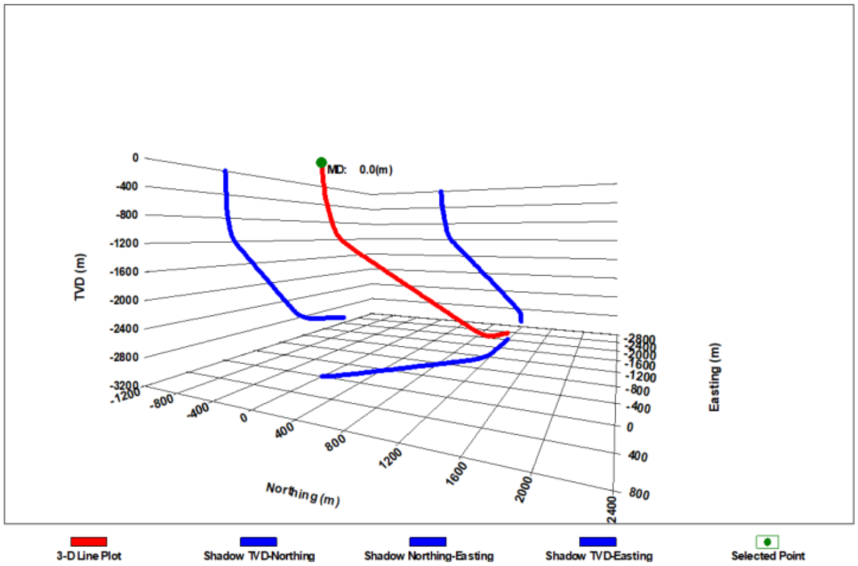

Figure 16—3D Plot of the Well 4

The CCT solids removal operation was successful on Well 4, so that 4200m depth was reached with total of three cleanout RIH attempts with vacuuming BHA. In total 1500 m section of well was cleaned from 5000 kg of the formation fines that was recovered at the surface sand filtration unit.

Well 5 (Figure 17): Well 5 drilled in Caspian Sea is an oil producer well completed with OHGP. Well had incomplete gravel pack at the toe and history of moderate sand production at early life period. The bridge plugs were set at 3900m to isolate poor gravel pack section. Few years later well had a water breakthrough and increased sand concentrations. Well was choked backed to mitigate potential sand failure but later same year the well failed. Drift and tag was conducted to investigate the cause of failure in the well. Slickline drift tagged HUD at 2660 m. Bailer sample was taken for analysis which indicated sand content. CCT was chosen as a best option for solids cleanout. The objective of intervention was to conduct CCT clean out operation to desired TD, and then run wireline conveyed diagnostic log to survey sand screen condition and attempt to determine the potential source of sand production and set the bridge plug above the damaged screen section.

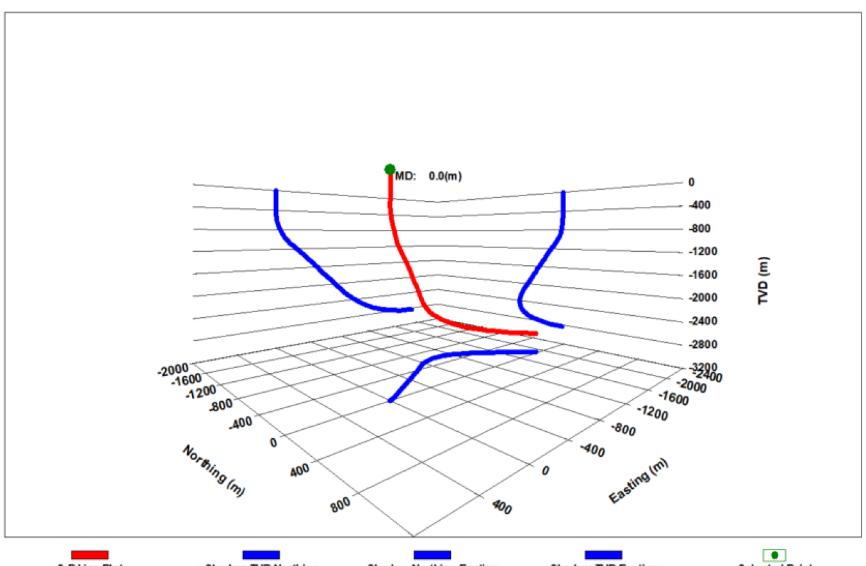

Figure 17—3D Plot of the Well 5

The well was cleaned out up to 3600m (950m). Overall two CCT RIH were performed to clean a total of 5200 kg of the sand from the Well 5. Cleanout couldn't proceed further due to CCT was stuck at 3600m, once string released and was back to surface the scratches were observed on vacuuming tool caused by damaged screens.

Well 8 (Figure 18): The oil producer Well 8 was completed with OHGP type of completion. Sand event occurred in 10 years later aligned with water breakthrough. The well had to be choked back and was operated at chocked back conditions in following years and next it was shut in due to excessive sand production. Several re-start attempts were conducted later that period without any success. Subsequent attempts demonstrated that although ~300 psig drawdown was given to the well there was no flow at all. The well was believed be completely sanded up preventing the inflow to the wellbore. As a solution to re-instate the production from the well two options were suggested. First option was to perform CCT Cleanout and if the required depth of 3680m is achieved, insert screens will be installed into well. The second option considered for the well was to cleanout with CCT minimum the depth of 3400 m in order to set the plug to isolate the lower zones and to perforate the upper production zone if the desired depth couldn't be reached.

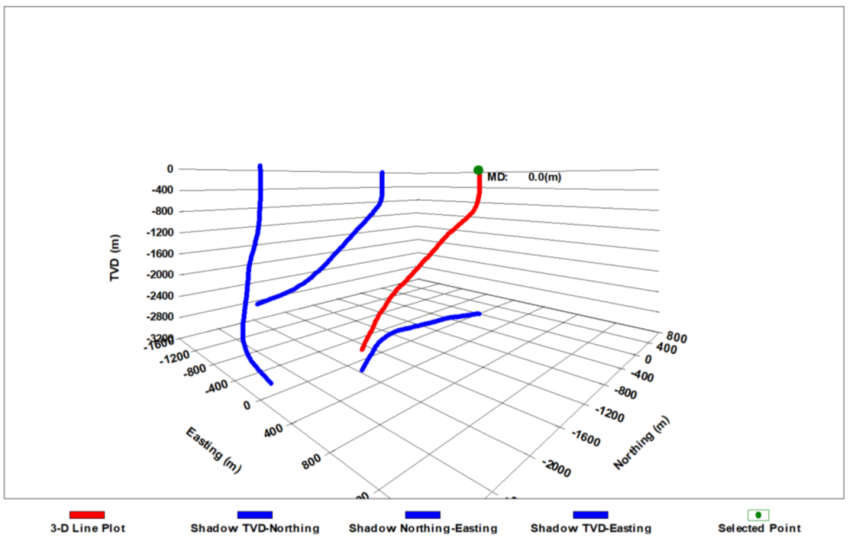

Figure 18—3D Plot of the Well 8

Overall, the CCT Cleanout on Well 8 is deemed to be successful in achieving the objectives set out in the scope of work. The drift run at the beginning of the operation revealed a HUD much above than the latest available HUD (3100 m compared to 3500 m) with the bailer containing fine sand. Further, via 2 CCT runs the cleanout could only progress till 3500m due to mechanical damage to top of the screens in well completion. In total, 400 m interval of the well was cleaned with 4400 kg of sand being recovered. Adhering to contingency plan, a drift run was performed from surface to 3400 m to confirm proper cleanout of the well. Next, the bridge plug was set at 3400 m and then the perforating guns were deployed and RIH on intelligent CT and successfully perforated the new production zone.

Conclusions

The application of the CCT Sand vacuuming technology helped to successfully remove the significant amounts of sand from many ultra-low pressure wells in the Caspian region. The technology resulted in successful solids removal where traditional methods of the sand cleanout have failed and provided the opportunity for operating companies for further remediation works on wells. Over 5600 m (18373 ft.) of fill was recovered from eight wellbores totaling 19600 kg (43210 lbs.) of sand.

Proper job design performed for all the CCT operations in the region has led to successful functioning of the vacuuming system and execution of the cleanouts.

The utilization of the 2"×1" CCT in the region showed better results than CCT string with 2 3/8" × 1 ¼" OD's as it has lower stiffness and helped to reduce contact drag forces and protect the coating of the wellbore components. Lessons learned from previous CCT operations were applied and there were no signs of damage to either the wellbore components or the CCT pipe itself.

Nomenclature

BHA: bottomhole assembly
BHP: bottomhole pressure
BOP: blow out preventer
CCT: concentric coiled tubing
CT: coiled tubing
HUD: hold up depth
M: meters
OD: outer diameter
OHGP: open-hole gravel pack
POH: pull out of the hole
P&ID: pipe and instrumentation drawing
RIH: run in the hole
TFA: tubing force analysis
TVD: true vertical depth
SSSV: sub-surface safety valve
WHP: wellhead pressure

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