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Going Long - Overcoming Challenges in Completing 3600m Laterals

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Abstract
Recent trends in unconventional oil and gas developments have seen longer horizontal wells drilled to achieve greater reservoir contact while minimizing cost and surface impact. Challenges for completing longer laterals include achieving effective fracture stimulation and performing clean out of the well bore after stimulation is complete. A case study was performed in Shell Groundbirch, an unconventional gas development in British Colombia, Canada, focusing on stimulation and extended reach cleanouts. Five long lateral wells +3600m lateral length with measured depth to true vertical depth ratio of 2.5, were drilled and completed; the resulting wells are 60% longer than the standard development well. Based on operational efficiency, coiled tubing (CT) was determined to be the preferred method for performing the millouts and well cleanup. 73.0 mm CT with an aggressive taper can reach the required set-down depths with enough weight on bit available to mill-out all completion plugs. Operational plans and milling tools were developed to maximize the probability of success. This paper outlines the technical details which contribute to an important case study that can help define and push the limits of extended reach CT interventions in industry.

Introduction
Completions technology, including coiled tubing extended reach techniques, has contributed to the economic and effective completion of longer horizontal wells. Shell Canada challenged the standard well design in Groundbirch to increase the well lateral length from 2200m to 3600m. The 60% longer completion design had to enable fracture stimulation evenly along the length of the wellbore while allowing for successful cleanup post stimulation. Coiled tubing was selected as the method to clean out the wells. The biggest challenge was to design and operate the coiled tubing string during the clean out of the lateral length. This case study will present the evolution of the coiled tubing design, considerations during design and execution, and results of the mill out operation.

Benefits of Extending Well Reach
A challenge in unconventional oil and gas plays is determining the optimum completion length of a well that accesses the technical limit of pay without increasing the risk to recover the reserves or impacting the production performance of the well. The benefits of extending reach in a well design are:

- Access more reserves with one well bore. This improves economics for the project when considering the total well cost (construct, drill, complete and connect with production facilities).
- Reduced environmental footprint. In unconventional resource type developments longer wells will result in fewer surface leases as the same length of pay can be accessed with fewer wells.
- Reduced dead space in development. Longer wells minimize the amount of unstimulated rock that is positioned between the toe and heel of two wells that would have been present in shorter well development.

Project Overview & Requirements
The Shell Canada Groundbirch Asset is in the Montney play of North Eastern British Columbia. Wells are drilled in pads of 3 to 13 wells, and are used to access multiple lobes of the Montney formation. The standard well ranges in lateral length from 1600m to 2200m with 2200mTVD to 2500mTVD. This case study examines the completion of a development pad where 5 wells were drilled to 3600m lateral length at a total well length of 6250m.

The first objective of the trial was to evaluate how the production contribution per meter of completed well changes over the extended lateral portion of the well. It was required to have full well bore access after stimulation in order to ensure the entire well bore was contributing to production. A production log was selected for evaluation, which has the requirement of milling out and cleaning the entire lateral post stimulation.

The second objective was to determine the technical lateral length limit, in terms of both drilling and completions without significantly increasing the well cost. A lateral length of 3600m was initially established as the technical limit based on initial well modeling. In addition, based on the acreage in the Groundbirch Area, 3600m was a length that technically impacted the development. There were very few land positions where a lateral length of over 3600m could be leveraged.

It is important to note that gaining access to the total wellbore of this length with coiled tubing is technically challenging. Generally speaking when the ratio of measured depth (MD) to true vertical depth (TVD) is greater than 2, techniques of extended reach are applied to reduce friction in order to reach depth before the coiled tubing string undergoes lockup. To demonstrate the degree of this projects challenge, Table 1 compares the well characteristics of this project to other case studies found in a non exhausted search through the SPE publications of coiled tubing extended reach. It shows that the work described in this paper is among the most challenging profiles for work done with coiled tubing reach without the use of a tractor.

Reference (SPE#)	Region	Category of Coiled Tubing Activity	Well TVD (m)	CT Total Depth (md-m)	CT Lateral Reach (m)	MD/TVD
94208 (Moore et al., 2005)	Sakhalin, Russia	with Tractor	2,612	9,373	6,760	3.59
164237 (Arukhe et al., 2013)	Saudi Arabia	with Tractor	2,896	9,113	6,217	3.15
170831 (Liston et al., 2014)	W. Canada	without Tractor	2,407	6,198	3,612	2.57
159574 (Griffin and Nichols, 2012)	Bakken Shale, US	without Tractor	2,580	5,520	2,939	2.14
127399 (Al-Buali et al., 2009)	Saudi Arabia	without Tractor	1,856	3,694	2,390	1.99
168250 (Burke et al., 2014)	Alaska	CT Drilling	2,768	4,077	1,309	1.47
106874 (Tongs et al., 2007)	W. Canada	CT Drilling	4,463	6,370	1,908	1.43
84162 (Patrick et al., 2003)	W. Canada	CT Drilling	5,460	6,605	1,025	1.21

Table 1 - Well characteristics of coiled tubing extended reach case studies worldwide (SPE Search)

Well Design and the Role of Coiled Tubing

Existing Groundbirch Wells

The Standard 2200m lateral well design in Groundbirch is a two string design with 244.5 mm (9-5/8") surface casing and 139.7 mm (5.5") production casing. No production liner is used. Standard well completion is a plug and perforate design with multiple perforation intervals per stage to establish limited entry design. Composite 139.7 mm frac plugs with carbide buttons are used as they establish isolation between stages and provide low risk and productive milling during well cleanup post stimulation. Tapered 60.3 mm (2 3/8") or tapered 66.7 mm (2 5/8") coiled tubing is used for the mill out, with the latter preferred for 139.7 mm completions. Friction reducers are used to minimize circulating pressures, fatigue on the coiled tubing, and reduce premature lock up. The goal is to mill out all plugs in a single trip with viscous pills pumped after compromising each plug in an effort to keep the well bore clean and limit friction in the well.

The milling bottom hole assembly for the well clean out of a standard 139.7 mm Groundbirch well consists of a 1mm under-drift roller cone bit and 73.0 mm mud motor that is optimized for 400L/min to 500 L/min circulation rates. These rates provide torque to efficiently mill and create annular velocities over 40m/min, effectively removing debris from the wellbore. A friction reduction tool is activated at these circulation rates to reduce the risk of premature helical buckling and lockup (Hilling et al, 2012). Other standard BHA components used include a diverting circulating sub, hydraulic disconnect, and a hydraulic reset jar in the event coiled tubing becomes stuck.

Long Lateral Well design

The 3600m long lateral well design was selected to maximize successful drilling to the planned target depth. The well, differs from the standard well design. The production casing string is a tapered 177.8mm (7") casing in the vertical section crossed over to 139.7 mm (5.5") casing at the heel (90°) in the lateral portion of the well. The larger casing in the vertical portion of the well was to help land casing at TD using additional weight. The completion interval is in the 139.7 mm portion of the casing to maintain the same casing size and near wellbore interface as with the standard length well design. This enables production comparison form standard to long lateral wells without addition of a variable. Table 2 shows the characteristics of the 5 long lateral wells drilled.

Well	PBTD (m)	TVD (m)	Lateral Length (m)	Ratio MD/TVD	Deviation @ 177.8mm to 139.7 mm XO
B	6250	2353	3550	2.66	90
C	6310	2423	3589	2.60	90
D	6320	2479	3611	2.55	90
E	6180	2354	3638	2.63	60
F	6283	2427	3676	2.59	42

Table 2 - Long Lateral Well Profiles

The base line of the design was plug and perforation as in standard Groundbirch well design, however cemented Frac sleeves were considered in the design for the last 5 to 6 stages of the well. Given the length of the well it was uncertain if coiled tubing could be used to clean out the entire lateral portion, and as a result frac sleeves were dismissed as an option. Larger outside diameter (OD) on the cemented sleeves or open hole packers yield higher friction factors when running casing which could risk landing casing to TD. Sleeve systems were also dismissed as there is some uncertainty over the production performance when compared to plug and perforate systems in Groundbirch, which would impact the ability to accurately perform comparative production analysis. Furthermore, there was an objective to run a production log post initial flow back to understand the production contribution over the entire length of the lateral. Having a sleeved completion may restrict access to the logging tools. As a result the well design was determined to be a full wellbore length plug and perforation with 139.7mm casing.

Determining a well intervention option that would enable access to the entire well was the key to having success in this design. The three objectives for this portion of the well completion design were to:

- Be able to reach total depth on the well with a set down force of 250 daN (560 lbf) to mill out the last plug or perform a well clean out in the event of screen out during stimulation operations
- Have adequate hole cleaning velocity in the vertical 177.8mm (7”) cased portion of the well. A minimum velocity of 40m/min (2.18 ft/sec).
- Avoid increasing the cost per meter of the completion on long lateral well design.

Extended Reach Frac Plug Millout Options

Coiled Tubing – 60.3mm and 66.7mm
Based on the standard Groundbirch well design, conventional coiled tubing practices were modeled and applied to determine if standard equipment used could be used in the proposed long lateral application. Standard applications of achieving maximum well depth were applied to modeling including – agitation tools, decreased friction coefficients under the assumption of a well clear of debris, and the use of metal to metal lubricants. These variables failed to achieve an acceptable set down force to successfully meet the 250 daN requirement. Figure 1 displays the force limitations of the strings that were available at the time for Groundbirch completions.

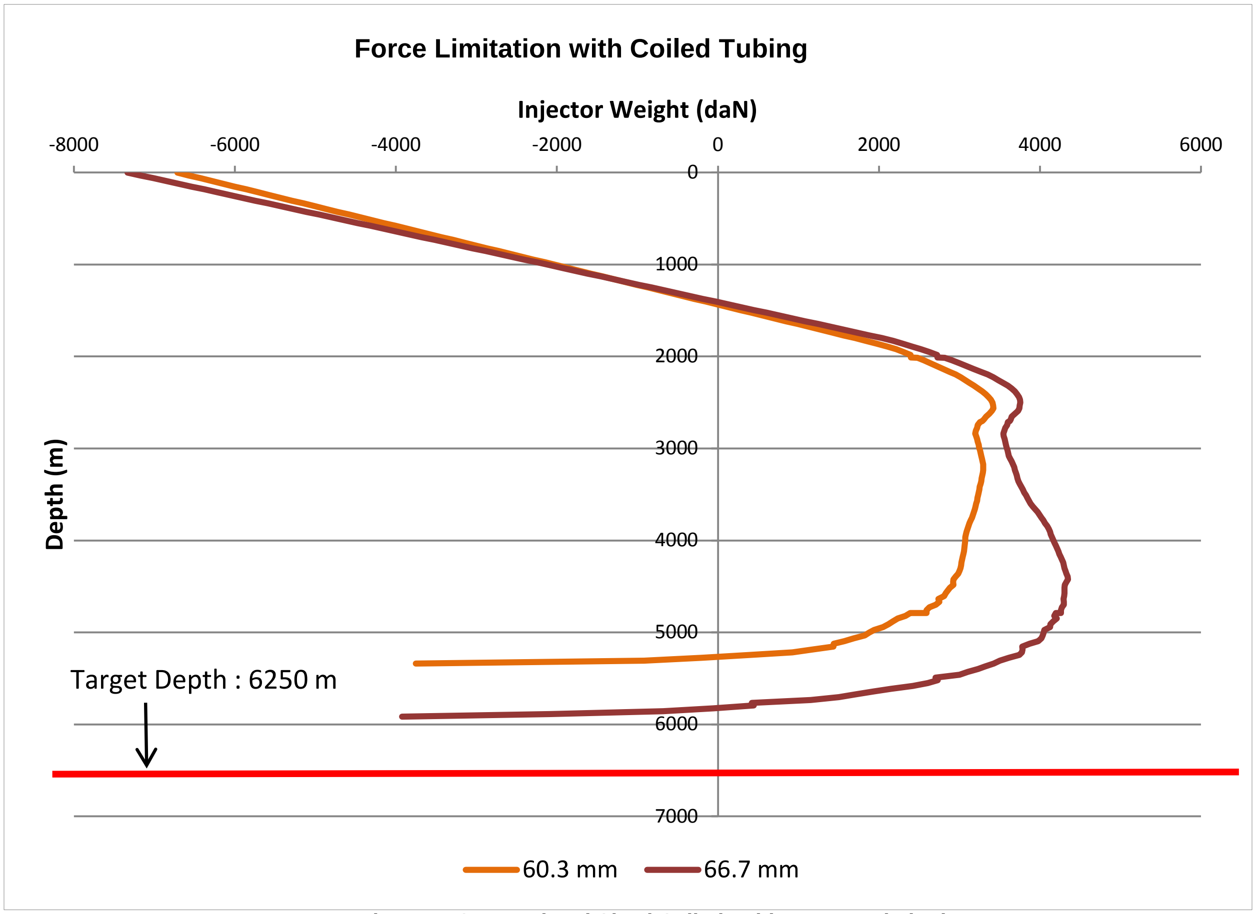


Figure 1- Conventional Sized Coiled Tubing Force Limitations

Limitations of existing equipment were not only constrained by the available set down force of the coiled tubing but also by the ability to achieve sufficient hole cleaning velocities and minimize coil fatigue. The acceptable fatigue limits were measured on the ability to complete the entire project without replacing the string to limit well cost. Table 3 shows all the limitations of available equipment at the development stages in the project.

CT Size	CT Wall Thickness	Max. Obtainable depth	Meets 6250 m Target Depth?	Max. Fluid Velocity	Meets min. 40 m/min Target Velocity	CT Fatigue	Meets Requirements
60.3mm (2-3/8")	0.156" – 0.224"	5400 m	NO	177.8mm Csg – 33.6 m/min	NO	No Concern	No
66.7 mm (2-5/8")	0.156" -0.250"	6000 m	NO	177.8mm Csg – 38.6 m/min	NO	Concern	No

Table 3 – Conventional Sized Coiled Tubing Operational Limitations

The inability of 60.3 mm and 66.7 mm coiled tubing to meet objectives was due to early lockup and insufficient annular velocities. Standard coiled tubing application for Groundbirch would not meet the long reach well objectives. Table 4 summarizes additional extended reach techniques that were considered to meet well objectives however they were not implemented (Newman et al., 2014).

Technique Considered	Description of Extended Reach Technique	Reason to Exclude Technique in Base Plan
Floating coiled tubing	Using Nitrogen to, (1) lighten the coiled tubing, reducing wall contact and string weight and increasing overall setdown force. (2) increase velocity for hole cleaning.	Nitrogen has a cost increase and can create operational challenges during milling operations
Coiled Tubing Tractor	Tractors can produce an additional traction force of up to 7000 lbs. Additional set down force would be adequate to complete the operation..	The risks related with running a tractor in this project with frac sand and plug debris proved too high. Losing the tool downhole would be of significant financial setback. Limited availability of tractor inventory in Canada
Pipe Straightener	Provides additional reach due to removing residual bending in the coil. Imparts additional fatigue that is undocumented and untested on available coil strings.	Bhalla (1996) explains that when using a pipe straightener there is a reduction in life of the coiled tubing between 14 to 23%. Tipton's et al. (2012) states that the life of straightened tubing is estimated to be about 70% of tubing run without straightener. Given the length and cost of the entire string as well as the requirement to use one string to mill out all 5 wells, a destructive element such as a pipe straightener with unsubstantiated wear on the string was deemed not worth the potential risk.
Friction Reduction Beads	Promotional papers from manufacturers quote cases where a 0.3 friction factor was reduced to 0.1 while utilizing beads. Polymer beads were considered as a backup solution but only if absolutely necessary	Adequate filtration systems would have to be installed during post well clean up and flow back to ensure no beads enter the production system as they can be detrimental to downstream equipment.
Change in well design	Consideration to include a tie back liner to surface with reduction in ID to 139.7 mm to reduce the impact of buckling of coiled tubing in the vertical portion of the well and increase cleaning velocities.	This well design change had significant increase to the well cost so was dismissed as a viable option.

Table 4 - Other Extended Reach Techniques

Hydraulic Snubbing Unit

The use a of hydraulic snubbing unit with a 73.0 mm work string to mill through frac plugs and to clean up the well bore was considered. Using a 73.0 mm work string enables adequate annular velocity for debris removal and modeling supports achieving required set down force at total depth. However, with a hydraulic snubbing unit there is a drastic increase in time on well compared to coiled tubing due to reduced run in hole (RIH) speed from making and breaking joints. This significantly increases the cost of the mill out and as a result was considered non-viable for the project.

Service rig

A service rig using 73.0 mm work string would enable adequate hole cleaning velocities and sufficient set down force at target depth to mill out the deepest plugs. The service rig also has reduced RIH speed compared to coiled tubing resulting in the same disadvantage of the hydraulic snubbing unit. Furthermore, the use of a service rig adds the complication of using an over balance mud system which could damage the stimulated formation. This creates additional risk to the completion rendering this a non-viable option for the project.

Fit-for-Purpose 73.0 mm (2-7/8") CT String Design

As the current coiled tubing equipment used in Groundbirch along with applied extended reach practices in industry did not meet project requirements, larger diameter coiled tubing was required. Figure 2 displays the extended reach advantage of 73.0 mm coiled tubing over conventional sizes.

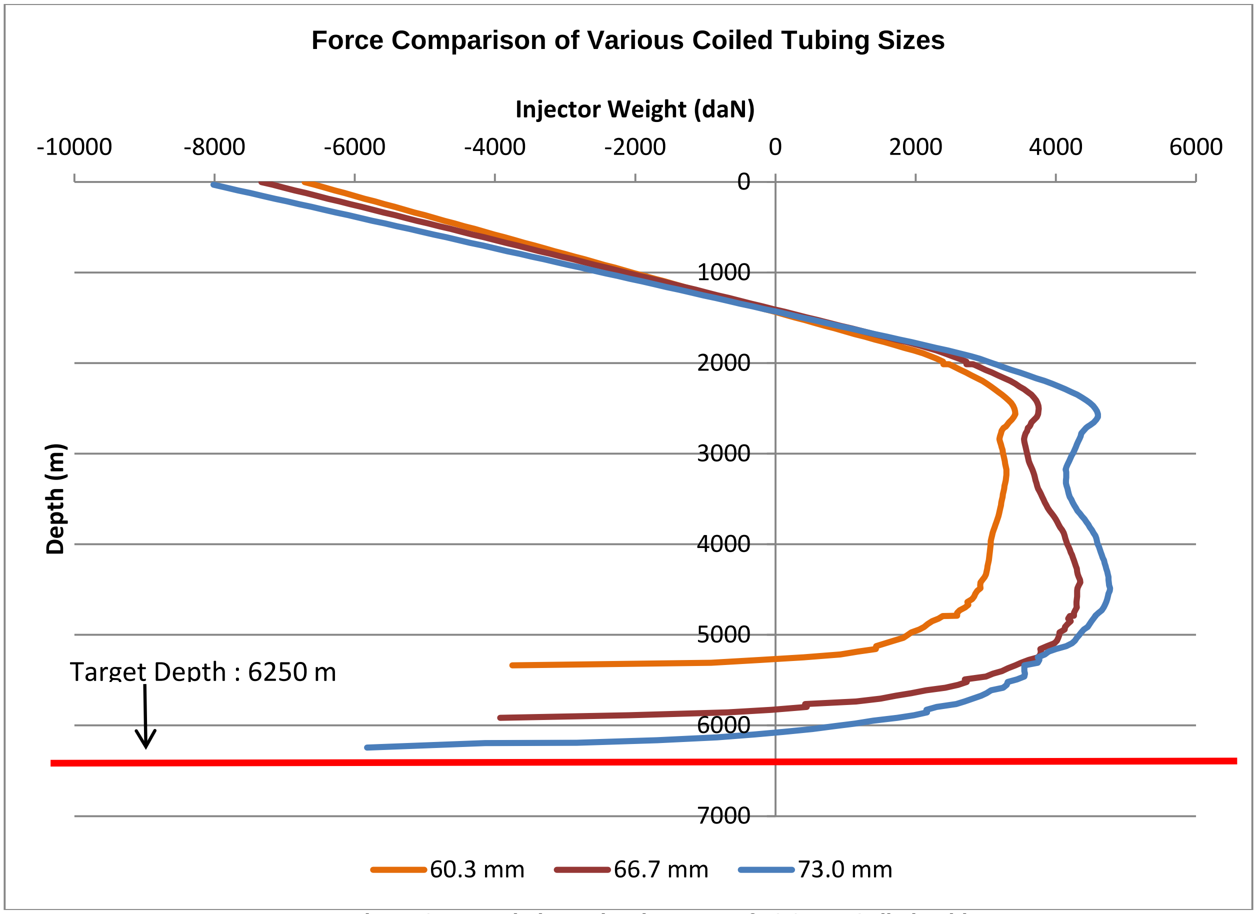


Figure 2 -Extended Reach Advantage of 73.0 mm Coiled Tubing

Table 5 shows the final design of 2-7/8" coiled tubing that was created to meet the requirements of the project.

CT Size	CT Wall Thickness	Max. Obtainable depth	Meets 6250 m Target Depth?	Max. Fluid Velocity	Meets min. 40 m/min Target Velocity	CT Fatigue	Meets Objectives?
73.0mm	0.156" – 0.250"	6250 m	YES	177.8mm Csg - 40.5 m/min	YES	Concern	YES

Table 5- Operational Advantages of 73.0 mm Coiled Tubing

Incorporating 73.0 mm coiled tubing into the milling operation fulfilled the requirements to complete the operation but presented a unique problem. As coiled tubing outside diameter increases so does the rate of fatigue at similar circulating pressures. A bottom hole assembly was designed and general operation parameters were determined to limit fatigue on the coiled tubing string.

Fatigue Limitations – Tool Design Considerations

To address fatigue issues a downhole tool was designed and manufactured. The design of a 79.38mm (3-1/8") motor provided a 50% pressure decrease when compared to the standard 73.02mm (2-7/8") motor design. This was coupled with a 79.38 mm friction reduction tool designed to operate at target circulation rates without excessive back pressure. The significance of this is not only to decrease pressure induced fatigue rates of the coiled tubing, but also to allow higher flow rates achieving hole cleaning requirements (Pawlik et al., 2014). Slim line coil tubing connectors were required to maximize the annular space between the milling BHA and the coiled tubing. This reduces the chance of plugging and maintains the ability to be 'fishable' in 139.7mm (5.5") casing. The tool assembly was designed with more durable bearing section to handle higher pump rates and extra torque while maximizing performance and minimizing deflection stress forces in the BHA. The new tool design is summarized in Table 6.

Motor Performance	Units	2-7/8"	3-1/8"
Torque Slope	Nm/kPa	7.76	12.71
Flow Range	lpm	190-650	380-800
Rotation	rev/l	0.98	0.59
Optimal Load -Pressure	kPa	7310	5450
Stall Pressure	kPa	10960	8200
Optimal Load -Torque	Nm	1190	1450
Stall Torque	Nm	1790	2200

Table 6 - Motor Size Performance Comparison

Fatigue Limitations – String Operation Considerations

The material grade selection for 73.0mm coiled tubing in a milling scenario was selected based on a combination of performance and economics. In this case, the anticipated pressures favored either a 90 or 100 grade design based on maximizing string life. The additional number of trips the 100 grade steel would have generated didn't provide enough benefit to warrant the increased cost. This is shown in Figure 3 where the 100 grade pipe has a much lower fatigue life at lower pressures and only a marginal increase at higher pressures. The plot shows the fatigue of 73.0mm coiled tubing with 4.45mm (0.175”) wall thickness. This was selected for modeling purposes as it was anticipated to be the thinnest wall being cycled over the gooseneck at milling pressure. The lower cost and near optimal performance of the 90 grade pipe was considered the best selection for this operation.

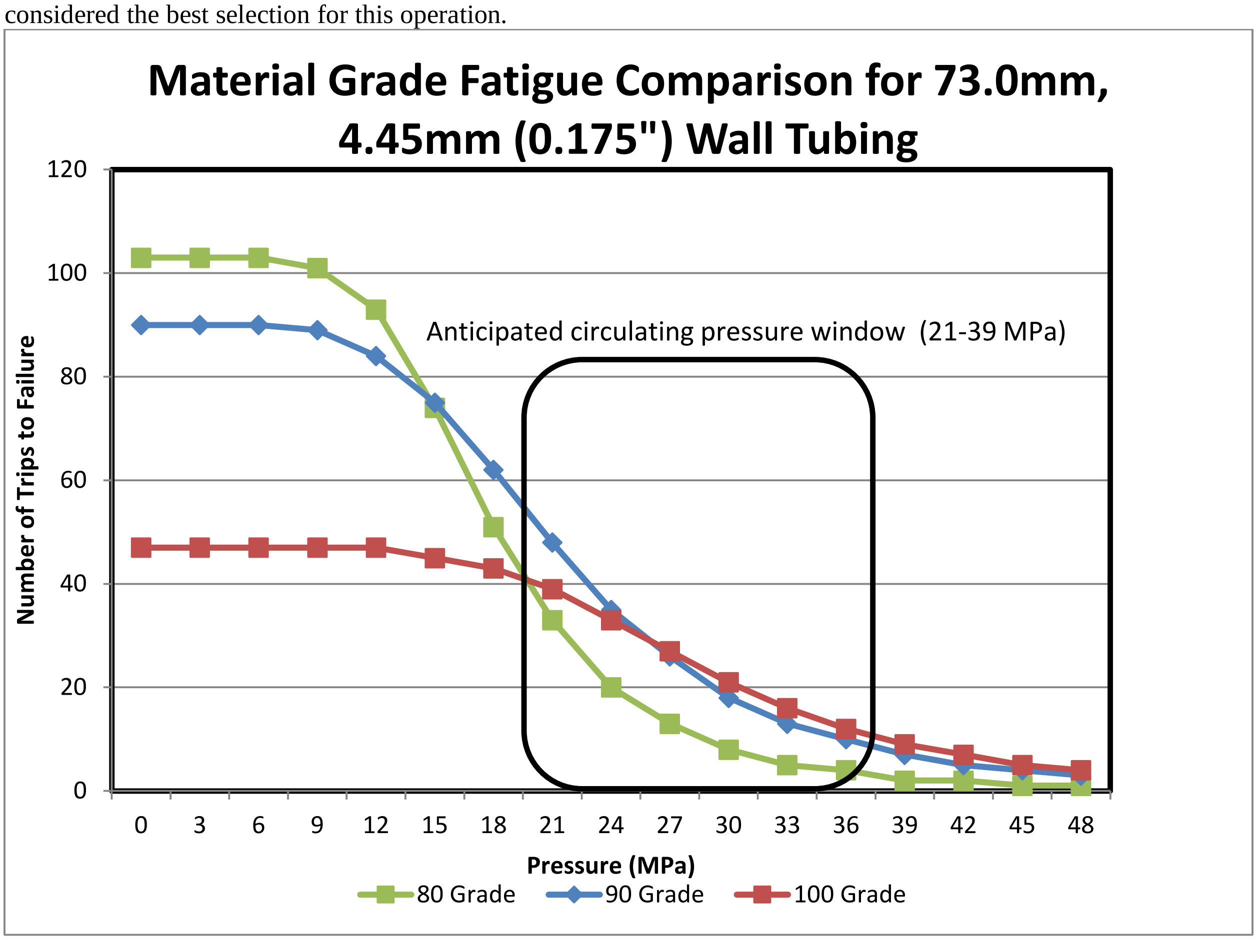


Figure 3 - Material Grade Selection

The final taper design of the 73.0 mm string was built to extend the lightest wall possible through the horizontal and increase in a short distance to the heaviest wall throughout the build. Fatigue modeling indicated that the 3.96mm (0.156”) wall would be ineffective for fatigue life management of the string if cycled at milling pressures. The string was then modified to incorporate a portion of 4.45mm (0.175”) wall thickness that would meet the required downhole force for maximum reach while handling milling and circulating pressures while traveling over the gooseneck. To be conservative for the project, the string was to withstand 3 cycle trips per well (total of 15 trips for the pad) in the event that wiper trips (short trips) were required to mill out each well. Figure 4 denotes the operating pressures that were anticipated throughout the operation with respect to fatigue modeling. It should be noted that all the modeling and live fatigue monitoring performed incorporated a 305 cm (120") gooseneck radius and 244 cm (96") reel core diameter. By utilizing larger dimensions for both the gooseneck and reel core diameter, fatigue is substantially decreased when compared to conventional surface equipment dimensions.

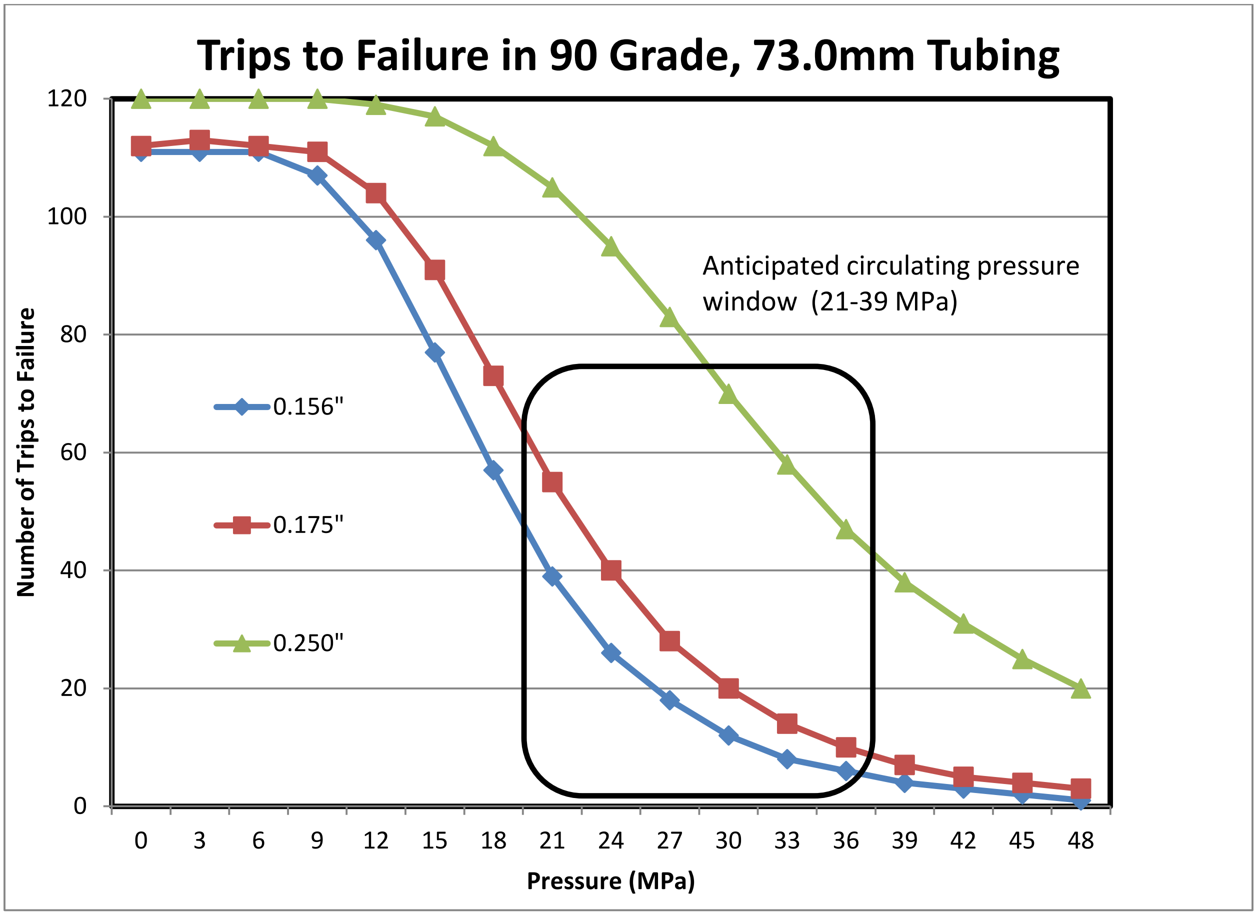


Figure 4 - Coiled Tubing Fatigue Parameters

Given the range of wall thicknesses and potential to incur high amounts of fatigue, a strict pumping and pressure control regime was implemented. This basic rate program was designed to be adjusted by the pump and coiled tubing operators when moving over different wall sizes throughout the operation. The 3-1/8" motor design was tailored to accommodate the necessity for a large variance in milling rates, from 400 L/min to 600 L/min or more. Table 7 shows the operation constraints for the designed 73.0mm tubing.

Wall Thickness (mm)	Wall Thickness (inch)	Start Depth (m)	End Depth (m)	Maximum Recommended Run in Hole Pumping Rate (L/min)	Anticipated Circulating Pressure (MPa)
3.96	0.156	0	2,068	150	10
4.45	0.175	2068	3,652	400	21-25
6.35	0.25	3652	6,564	600	35-39

Table 7 - 73.0 mm coiled tubing pumping schedule controlling pressures and fatigue while maximizing hole cleaning capabilities

Logistical Challenges

Currently in onshore North America 73.0 mm coiled tubing is not employed as standard service for extended reach laterals as previously there was little demand due to its increased weight and difficulty associated with transportation. Canada represents a challenge in heavy transportation as seasonal road bans require larger wheel bases and increased axles and wheel count.

During the initial planning of the long lateral project coiled tubing trailers available were limited in capacity to run an extended reach 73.0 mm coiled tubing string.

A new trailer was designed to hold the required length of 73.0 mm coiled tubing string for the project. Trailer dimensions were increased from 10.5' to 12' in width and the lifting lugs were improved and rated for 180,000lbs of lifting weight. The result was an improved reel capacity displayed in Table 8.

	Reel Capacity (m)		
	60.3mm	**66.7mm**	**73.0mm**
Original Design	7,774	6,160	5,330
Improved Design	9,900	7,900	6,800

Table 8 - Reel Capacities for different sized coiled tubing

Care and planning had to go into road transport routes in advance to obtain required permitting and ensure that the coiled tubing could be delivered to the well site location on time. Large coiled tubing reel weights and road weight restrictions meant that considerable effort was needed to ensure a reel trailer design that was both functional and distributed the load adequately over enough axles.

Operational Results & Troubleshooting Performed

Fracture stimulation operations were completed and the challenges seen foreshadowed many of the issues that would later be seen in the millout operation. During stimulation operations one challenge that was observed on the B, C, and D wells was pumping the composite bridge plugs on wireline though the 177.8mm to 139.7 mm crossover point at the heel of the well. Sand buildup in the casing crossover settled out during stimulation and impeded bridge plug movement during pumpdowns. The sensitivity of the crossover location was amplified by the sensitivity and technical aspects of long reach coiled tubing operations.

The first coiled tubing milling operation, performed on the B-Well, represented the greatest challenge of the project as it combined a highly tortuous wellbore path with largest step out and with a casing crossover point set at over 50 m into the horizontal leg. It also involved the trial and error lessons that would increase efficiencies later in the pad. The well millout consisted of 3 phases explained in the section below.

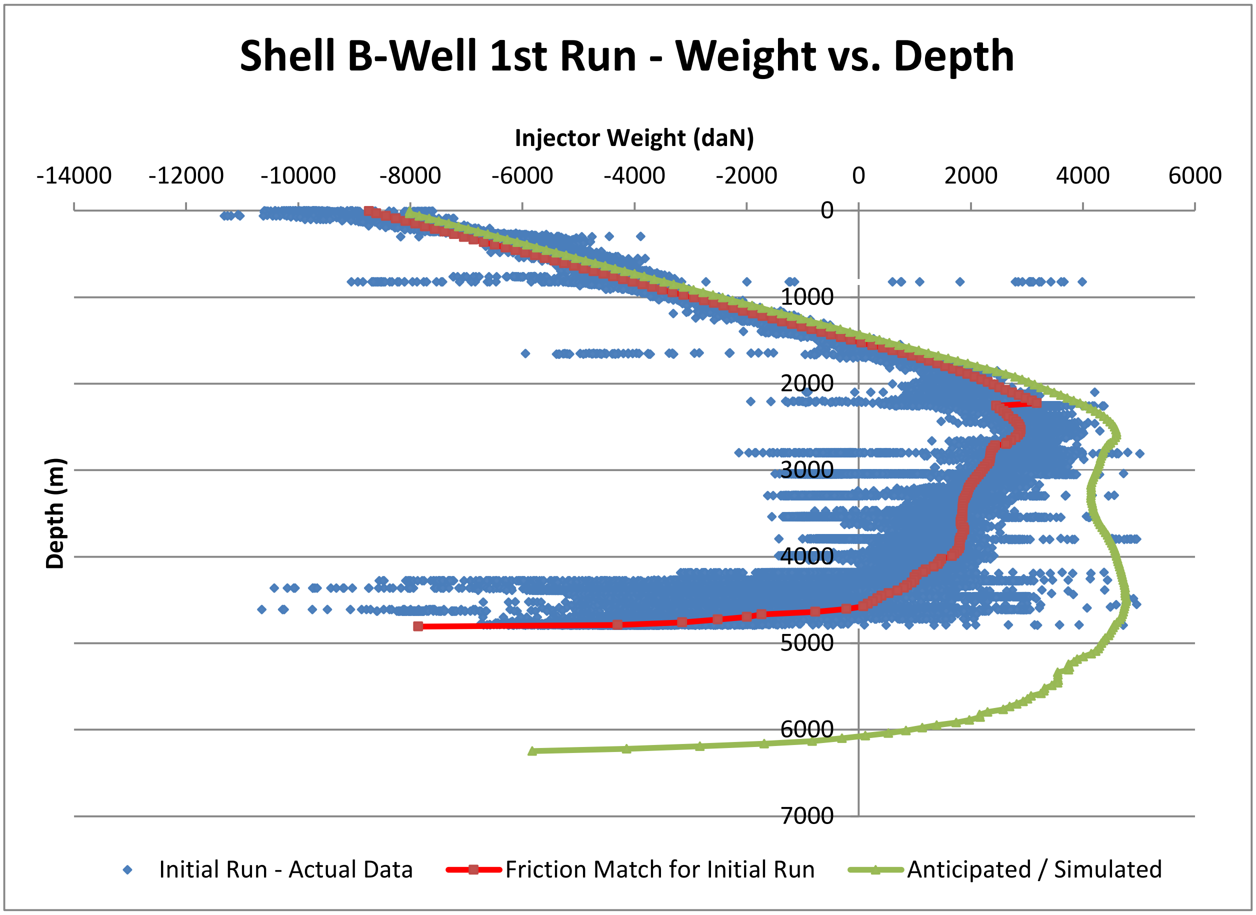


Figure 5 - B-Well, Initial Run

Phase 1: Initial Coiled Tubing Mill-Out Run

Figure 5 shows the comparison of the actual weight vs. depth data to the predicted. The first six plugs were milled out as per program; however, after the 7th plug was milled signs of lockup were detected. The 8th and 9th plug were milled using metal to metal lubricant and the decision to perform a wiper trip to the crossover to assist in hole cleaning was made. The maximum depth achieved on this run was 4790 m. The surface weight seen compared to the modeled showed much higher than anticipated friction factors, mainly in the crossover point. This supported the decision to perform a wiper trip to remove sand or plug debris that had settled at the crossover of the 177.8mm to 137.9mm casing. Friction modeling also indicated a higher than normal amount of axial force generated against the coiled tubing. The initial run in hole successfully milled out 9 bridge plugs before a wiper trip was performed.

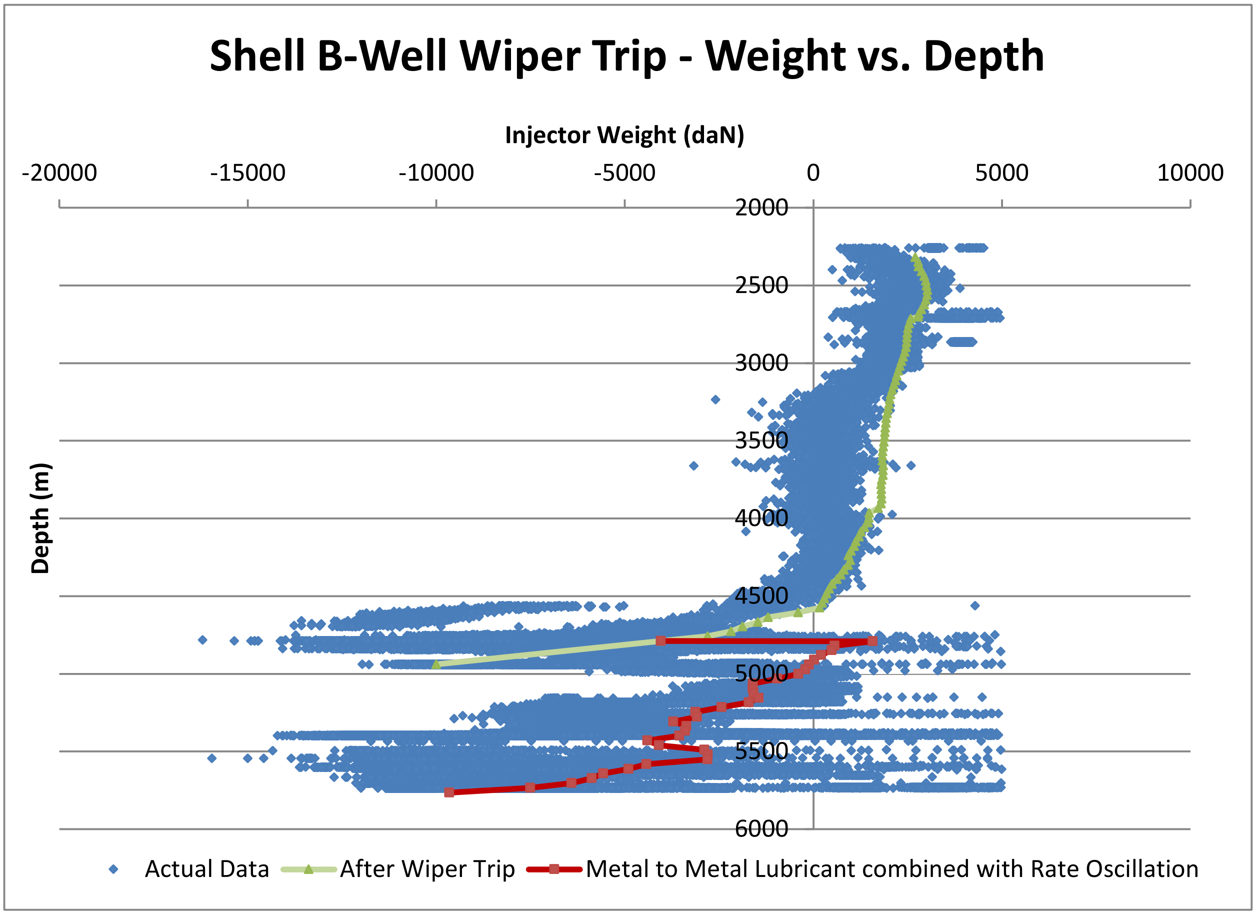


Figure 6 - B-well, Post Wiper Trip

Phase 2: Wiper Trip

Figure 6 shows the weight vs. depth data post wiper trip. After performing a wiper trip to the crossover section, milling operations continued with additional challenges. Friction issues and lockup occurred at roughly the same depth as the prior run. Post job friction matching indicates that the wiper trip had no benefit on reducing downhole friction issues and a large amount of force (over 1400 daN) was being hydraulically generated against the coiled tubing due to high circulation rates. Large volumes of multiple types of metal to metal lubricant were pumped with little benefit. The friction lockup curve seen in Figure 6 was altered by oscillating the rates from 0 to 600 L/min every second and generating a stiffening effect on the coiled tubing itself. The effect of the rate oscillation from a friction modeling standpoint lessened the amount of axial force acting against the coiled tubing from 1450 daN consistently to -785 daN. The final result was milling the 10th to 15th plugs at an average increase of 260% more time compared to the time average on the first 9 plugs. At this point, because of slow mill times the decision was made to pull to surface to inspect the BHA.

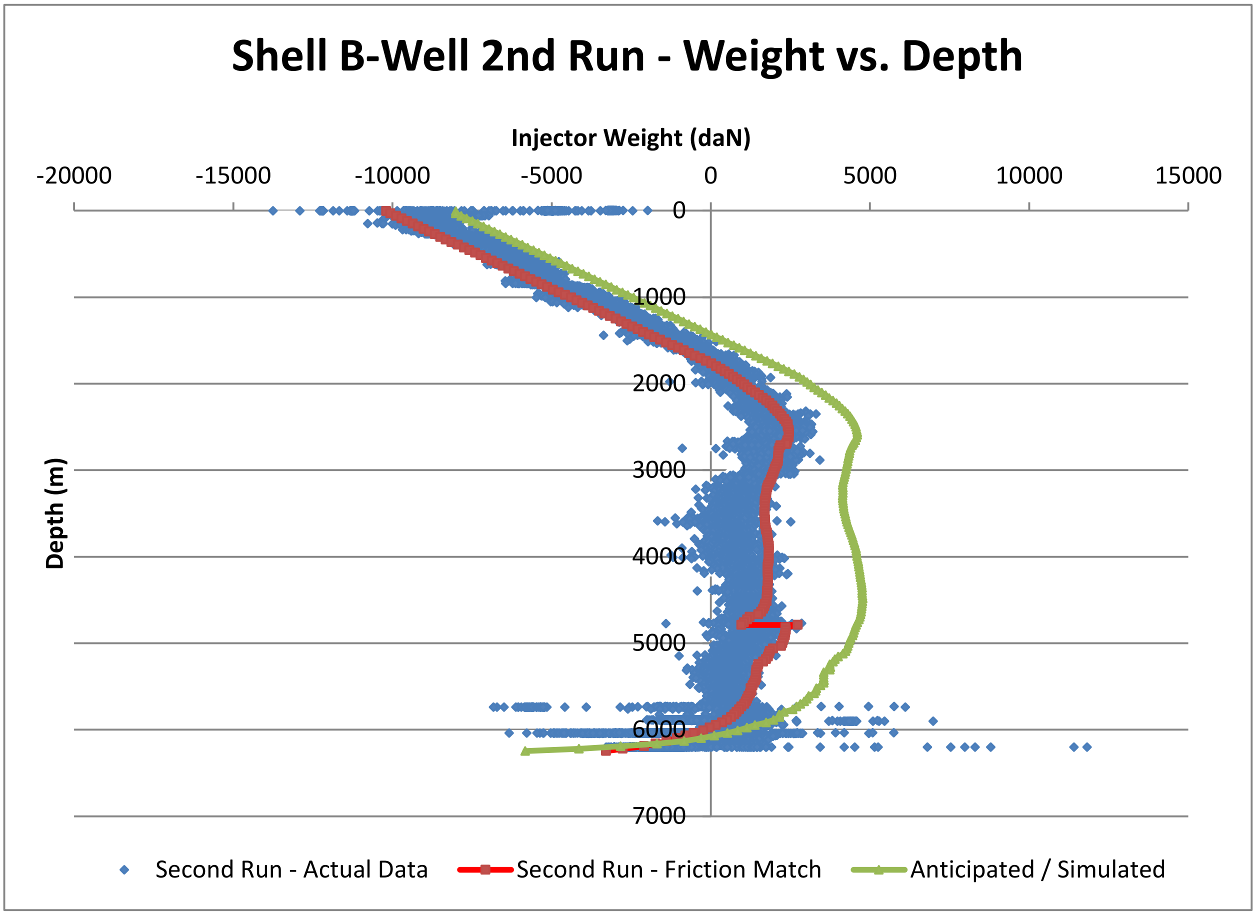


Figure 7 - B-well, 2nd Run

Phase 3: Second Coiled Tubing Run

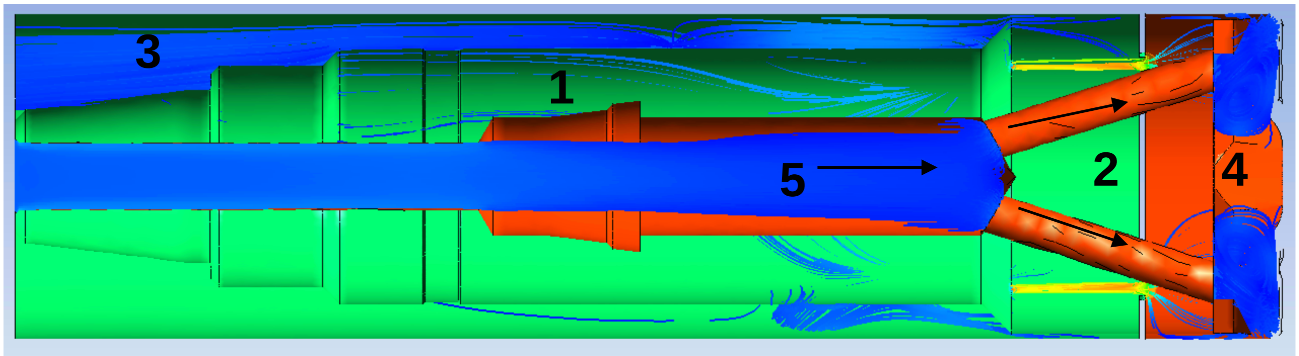
Analysis of the BHA resulted in the decision to install a ported bit sub with rear facing jets. This was added to redirect flow at high velocity to primarily assist with hole cleaning, and secondarily reduce the hydraulically generated force acting against the coiled tubing. The result, as shown in Figure 7, was the successful millout of the remaining 3 plugs in the B-well with little complication. Post job friction matching indicates that the full wiper trip to surface had a minimal effect on reducing pipe friction downhole.

Post Job Analysis

Friction coefficients remained constant throughout the milling operation of the B-well. In order to closely friction match to actual data, multiple different friction coefficients were used in order to attempt to create a more dynamic model. The vertical section was friction matched with a friction coefficient of 0.27, the build was 0.28 and the horizontal ranged from 0.24 to 0.16. It was determined that the build section, specifically close to the crossover, accumulated debris throughout the operation which hindered pipe movement.

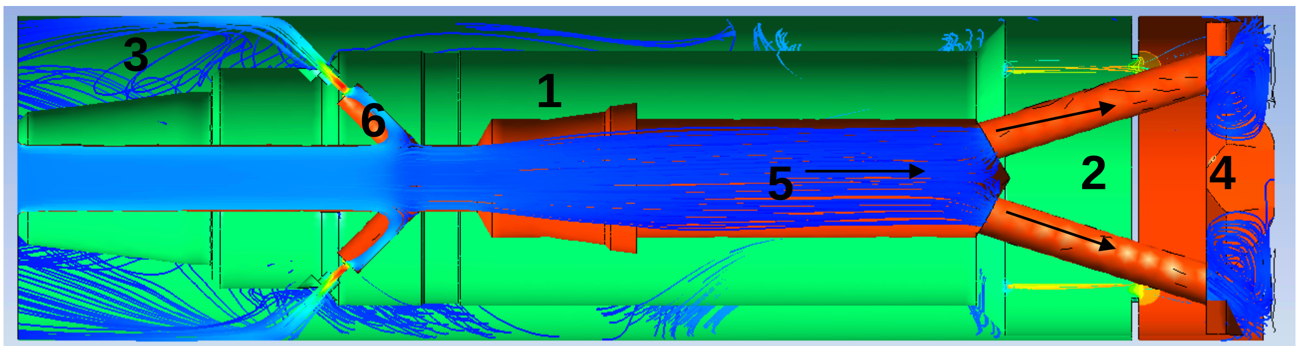
After adding the ported bit sub combined with rate oscillation the simulated axial forces acting against the coiled tubing were greatly reduced. Initial modeling indicated a force of 1450 daN acting against the coiled tubing at milling rates. Utilizing the ported sub and rate oscillation, this force appeared to be equalized and in some cases there appeared to be a “tractor effect”, adding 100 daN of downward pull.

To simulate the effect of the ported sub a model was constructed consisting of a rotary sub and JZ Bit both with and without 4 bypass ports. The models were then used as input to the Ansys CFX Analysis package where obstructions were simulated in the annular area between bit and the casing wall. These “obstructions” reduced annular flow area ranging from 30 to 90 percent. The effects of the obstructions coupled with the bypass ports were studied with respect to the hydraulic lifting forces between the mill and the plug. Hydraulic lifting forces refer to the proposed axial forces generated against the coiled tubing due to high flow rates. The images from the CFX Analysis below compare the different dynamic fluid movement through a 90% blockage scenario both with and without bypass ports. Both models were run with a flow rate of 800 L/min. The color on the plots represents velocity, with dark blue representing low or no velocity and the yellow and red representing higher velocities. The streamlines represent fluid flow, as shown in Figures 8 and 9. This evaluation of this model supported that the “tractoring” force observed on the 73mm coil tubing was due to the lifting force generated by the BHA.



1. Milling BHA 2. Bit Assembly 3. Annulus between Milling BHA and 139.7mm Casing 4. Bit/Plug Interface (Blockage) 5. Forward Circulation Through BHA

Figure 8 - Ported Bit Sub - No Bypass Ports -800 L/min with 90% Blockage



1. Milling BHA 2. Bit Assembly 3. Annulus between Milling BHA and 139.7mm Casing 4. Bit/Plug Interface (Blockage) 5. Forward Circulation Through BHA 6. Backwards Facing Nozzles

Figure 9 - Ported Bit Sub - With Bypass Ports - 800 L/min and 90% Blockage

Overall Coiled Tubing Milling Results

After milling, flowback returned large amounts of debris, presumably returned from the crossover point. The 177.8mm to 139.7mm crossover positioned at 90° in the B, C, and D wells, as per Table 2, contributed to early lock up during the milling operations. The crossover positioned higher in E and F wells resulted in less debris hold up at the heel of the well and contributed to more efficient milling operations. To enhance hole cleaning over the crossover, a high rate ‘bottoms up’ was pumped mid wiper trip directly over the crossover. The ported bit sub and rate oscillation technique coupled together reduced milling time and slip time throughout the project. Milling time refers to the instant the mill is set down on the plug to the moment the end of the coiled tubing is through it. This includes stalls but not back reaming or hole cleaning procedures. Slip time refers to the amount of time it takes to travel between plugs. This includes smaller wiper trips, back reaming if required and pumping gel sweeps and friction reducing chemicals. Figure 10 displays the summary of the milling and slip time in order of the wells completed.

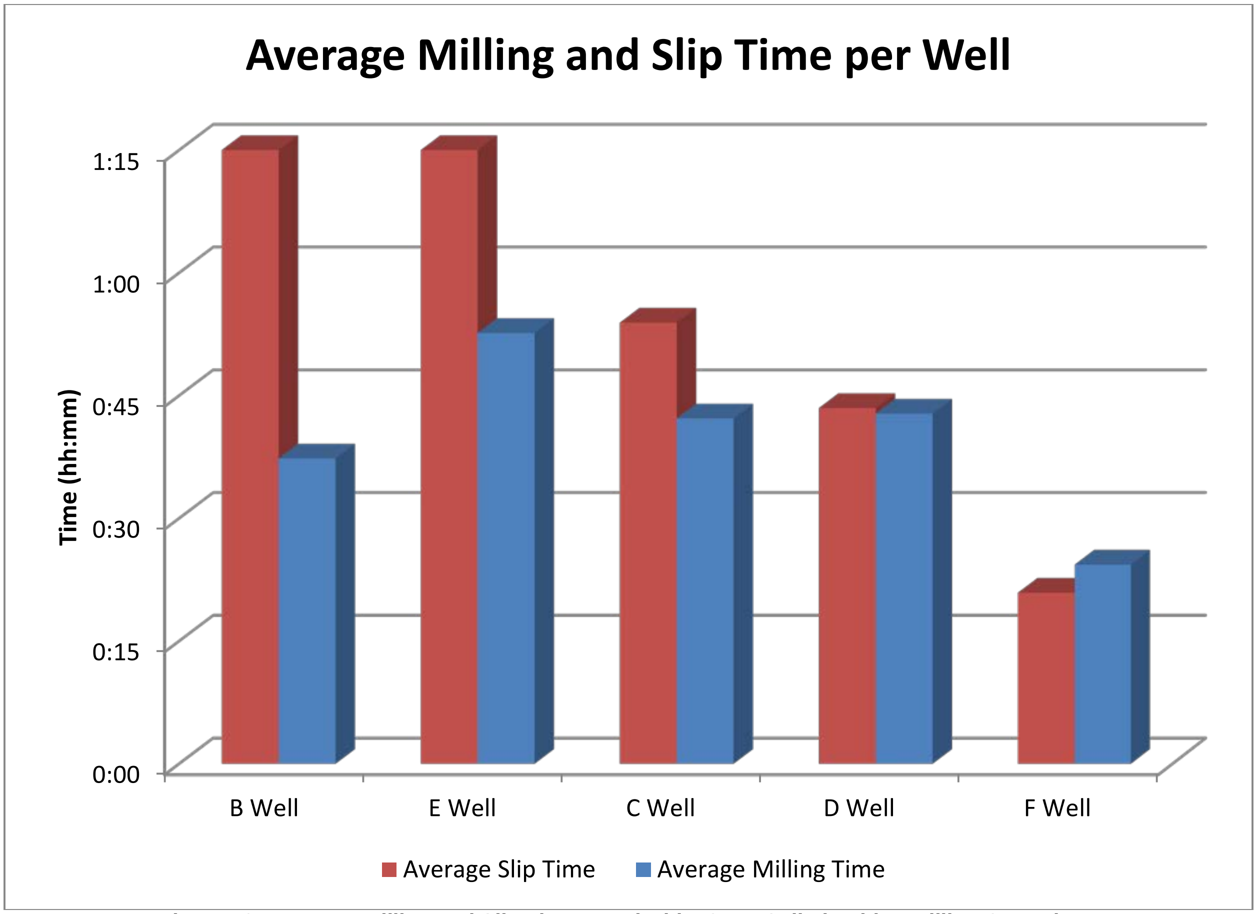


Figure 10 - Average Milling and Slip Time Trend with 73mm Coiled Tubing Milling Operations

As milling times and slip times reduced so did the overall time spent on each well, as seen in Figure 11. Time was measured from the moment of opening the master valve to the closing.

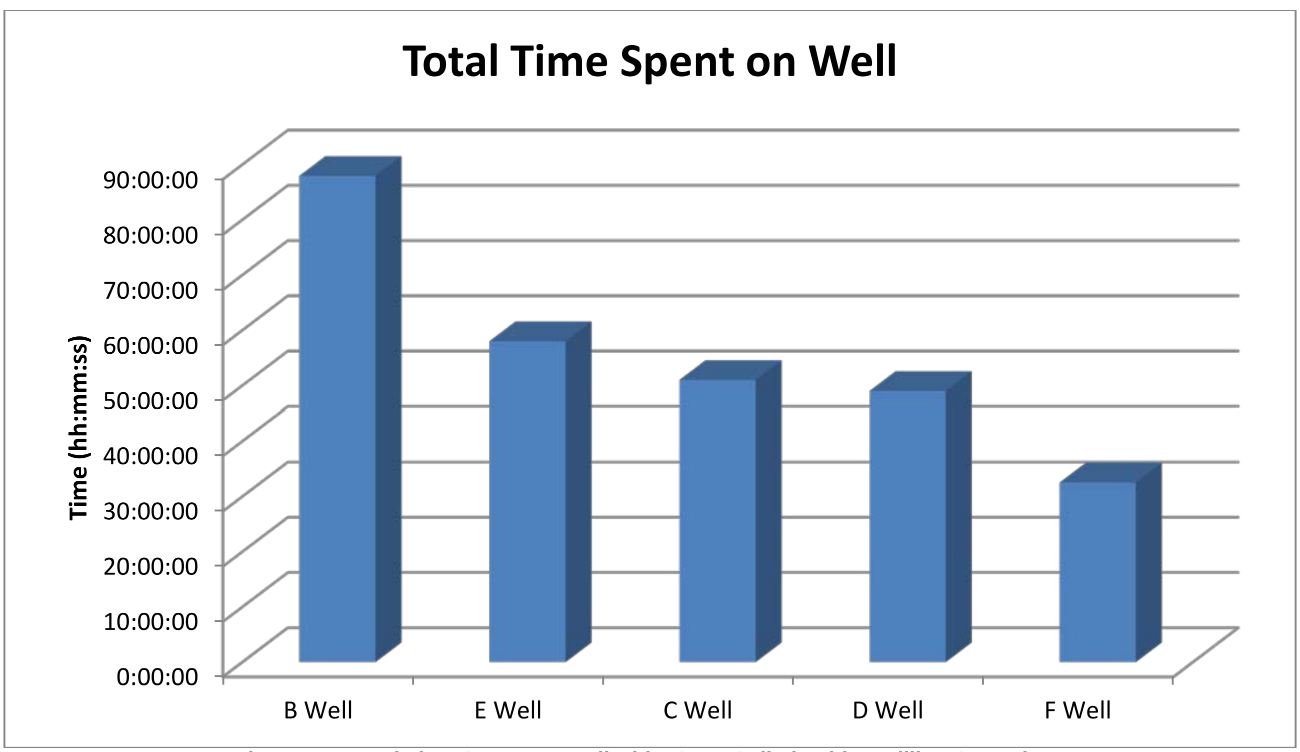


Figure 11 - Total Time Spent per Well with 73mm Coiled Tubing Milling Operations

A primary goal of the operation was to utilize one single coiled tubing string before it accumulated a necessary amount of fatigue for retirement. This goal was reached with 60% of useable fatigue life left on the string as can be seen in Figure 12. This success can be attributed mainly to 3 factors:

- The high rate versatile 3-1/8” motor: this had the benefit of greatly reducing circulating pressure coupled with a high stall torque of 2200 Nm. The result was the millout of 87 bridge plugs with only 3 stalls.
- Strict pumping procedures: tailoring rates to different wall thicknesses in order to reduce fatigue. This was coupled with the experimentation of anionic and cationic fluid friction reducers to best suit the salinity of the water. The result was a satisfactory control of pumping pressure to mitigate fatigue rates.
- Coiled Tubing Taper Design: the built for purpose 73.0 mm string incorporated fatigue life into the design and maximized wall thickness where anticipated high pressures and cycling trips were to occur. The result was a minimal amount of fatigue incurred in any single location throughout the operation.

Figure 12 - Accumulated Project Fatigue During Millout

Conclusions & Recommendations

Longer lateral wells increases the amount of accessed pay per well, resulting in a fewer number of well pads required for area development. This not only reduces the environmental foot print of the development but can have improved economics. Completions technology, including coiled tubing extended reach techniques, has played a large part in being able to economically and effectively develop longer lateral wells. Shell Canada Groundbirch was able to successfully mill out and clean up five long lateral wells to ensure full wellbore access for production evaluation. At the time of writing this paper analysis of production contribution from the extended lateral portion of the well was not available. The following conclusions are drawn from this operation:

- In trials, multi-well pad completions enable operators to leverage lessons from one well to another. In this case study this resulted in drastically reduced plug milling time and slip time, to increase operational efficiency of the project.
- The use of 73.0 mm coiled tubing in a post stimulated well clean out is a viable solution for extended reach applications for onshore unconventional oil and gas. Adequate pre-job assessment and planning is required to ensure proper route selection to mobilize larger and heavier weight reel trailers.
- Aggressive taper in 73.0 mm coiled tubing applications can increase achieved lateral length by reducing the tubing weight in the horizontal. Given the susceptibility to fatigue of thin wall in larger diameter coiled tubing, it is recommended to develop strict operational practices to reduce applied pressures to the thinnest wall tubing to maximize string life. The selection of 90 grade pipe was the optimal choice for the pressures of this operation based on overall string life and economics.
- In 73.0 mm coil strings where higher circulation rates (+550 L/min) are required, an appropriately sized milling bottom hole assembly will reduce exerted pressure on the coiled tubing, minimizing string fatigue. At higher circulation rates it is recommended to use a tool assembly that will reduce the hydraulic axial forces against the coil tubing through reverse facing nozzles enabling improved extended reach and improved well bore cleaning.
- Where well design enables, crossovers for casing size change should be placed at less than 90° inclination to limit debris hold up in the heel that can contribute to higher than expected friction factors during coiled tubing intervention.

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Glossary and Abbreviation Descriptions:
Agitator - A vibrational tool, activated by flow rates, at the bottom of a coiled tubing string. The vibration provides friction mitigation by a downhole pulsation that attenuates along the length of the string.

Axial Load - Force applied along the length of the coiled tubing string. Tension is positive while compression is negative.

BHA – Bottom Hole Assembly; in coiled tubing, the bottom hole assembly describes all specialized tool sections added to the free end of the tubing string to perform specific tasks down hole. The BHA can range from a simple nozzle to a complex system of resettable packers, mechanical locating instruments, logging devices and more.

CT – Coiled Tubing

Fatigue - The amount of wear put on the coiled tubing as it is bent and unbent to perform dowhnole operations. There is a finite life of a coiled tubing string based on the pressure and the number of bends a pipe goes through in its life.

Friction Coefficient (factor): - the magnitude of friction generated between the coiled tubing and well casing. As the friction increases, based on wellbore conditions, the ability to run in hole becomes more challenging.

Helical Buckling – Upon initiation of a compressive load, the coiled tubing will begin to form a helix in the well casing. Additional friction is encountered due to increased wall contact which may lead to lock up.

Lock up – The point at which the helical buckling of the coiled tubing against the well casing reaches a point where no there is no possibility of weight transfer from the surface to the bottom of the coiled tubing string. Forward movement is stopped if this occurs.

Pad- multiple wells drilled from one surface location.

PBTD – Plug Back Total Depth; the total depth of a well after casing and cement plug have been set.

Taper Design - A coiled tubing string design that incorporates different sizes of wall thickness. The outside diameter remains constant throughout the pipe while the inside diameter varies.

TD - Total depth; the deepest the well is drilled to prior to running casing.

Tractor : A dowhnhole tool that utilizes flow rates to rotate wheels that are pressed against the casing, providing extended downhole reach with coiled tubing.

Wiper Trip (Short Trip): The practice of retracting the coiled tubing string in the wellbore, to the portion of the wellbore that was thought to have debris hold up (usually into the build section of the well). Circulation is maintained to remove or clean debris along the wellbore to this point where a bottoms up clean is completed.

Unit Conversion:
1 Meter (m) = 3.28 feet

100 Millimeters (mm) = 3.94 inches

1 Megapascal (MPa) = 10 bar = 145 psi

100 Litres (L) = 0.6289 Barrels = 26.4 Gallons

1 Decanewton (daN) = 2.25 pounds-force

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