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The First Upward Swarf-less Section Mill Deployment in Asia Pacific – Save 50% Milling Duration

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Abstract.
Several wells in South Sumatera area have experienced with well integrity problem of high sustained casing pressure in B annulus (9 5/8" – 13 3/8" casing annulus); and required restoring well integrity of the annulus during P&A work. Barriers need to be in place to restore the well integrity. To install barrier in such condition, the annulus must be accessed by means of section milling. The section mill operation will be performed on the 9-5/8" casing and regain access to 13-3/8" casing in a particular depth interval.

There were 2 wells (Well X and Y) that were the subject to the section mill operation on 9-5/8" casing. Conventional Section Milling System was performed on well X; however, the Conventional System came with its own challenges such as, mechanical stuck pipe incident on well X which significantly increased the operation time, tons of metal swarf was returned at surface which increased the HSE risk greatly during clean up at surface and disposal and rate of milling penetration was limited by swarf handling.

In the second well Y, 9-5/8" upward swarf-less section mill system was deployed to overcome the challenges from the first well. With its Innovative upward direction section mill using left hand motor and auger assembly, the technology eliminates all swarf to surface and gives multiple added value. Firstly, it enabled 50% less time to perform section milling. Thus, the carbon emission from the operation was significantly reduced as well. Secondly, no swarf (milled casing debris) was returned to surface. Thus, it eliminated stuck BHA tendency, risk to damage surface equipment, and reduced environmental impact.

After the 9-5/8" upward swarf-less section mill had been done, operator was able to set an inflatable plug across the section-milled depth without encountering any issue, put cement column, and eliminate sustained casing pressure. 9-5/8" upward swarf-less section mill system saved 3.5 days of rig time compared to the previous section milling operation. By having this operation's duration optimization, 4.6 tons of carbon emission was reduced.

Globally, the technology had been run 4 times since 2018 and this project allowed to bring the technology the first time in Asia Pacific in 2022.

Keyword(s): Plug and Abandonment; Section Milling; Reduce Time; Eliminate Milling Debris; Well Decommissioning.

1 Introduction

Well X and Y was completed in 1990 and had been produced from TA Formation. The wells were no longer put in production because there has been water load up which is at the water contact depth and there is no HC potential anymore in well X and Y. These 2 wells have integrity problems in the presence of B-annulus with pressure ranging from 300 – 1200 psig, thus well integrity of the annulus need to be regained with plug and abandon work. Barriers are required to be in place to restore the well integrity. To install barrier in such condition, the annulus must be accessed by means of section milling.

Section milling is a conventional method for casing removal during plug and abandonment (P&A) operations where annular well integrity is compromised or questioned. The removal of casing by milling a window re-opened access to the formation, enabling placement of a rock-to-rock barrier[3].

The section mill operation was performed on well X and Y's 9-5/8" casing to regained access to 13-3/8" casing in a particular depth interval.

2 Conventional Section Milling Case History

Conventional section milling was performed on well X to mill 15m section of 9-5/8" 53.5 lb/ft casing. After conducting a surface test, the 8.5" BHA was then tripped in hole to cut out depth of 220m. The string was rotated to 65 RPM with 344 GPM. After several minutes, a 700 psi pressure drop was observed at surface, confirming the cut out was successfully made.

Following the cut out, 5,000 lbs weight was set down on casing stub and thus section-milling operation was continued with average rate of penetration of 0.75m/hr while maintaining parameter: 65 RPM/ 387 GPM/ 1100 psi/ 5klbs WOB/ 2klb-ft torque. Although hydraulic analysis and fluid plan had been carried out to achieve hole cleaning requirement with parameter: 310 GPM/ 60 RPM, when reaching depth 229.5 m, the string was stuck due to accumulated swarf downhole. 50klbs over pull was applied on string but no movement was observed. Work on pipe was then performed while maintaining the flowrates of 387 GPM. After several hours of working on pipe, the string freed and was continued to pull out to surface.

Consequently, the 2nd 8.5" section mill with new knives was tripped in hole to previous milling depth of 229.5 m. Milling operation was continued while maintaining parameter: 65 RPM/ 387 GPM/ 1100 psi/ 5klbs WOB/ 2klb-ft torque until reaching target depth of 235 m. Thereafter, the well was circulated clean by using high viscosity pill for 2x bottom up until no swarf was found at surface.

However when string was about to trip out from hole, the string experienced stuck pipe event. Jarring up and down operations were carried out to free string from its stuck point. After 27 hours of efforts, the string was finally free. Then, string was tripped out of hole. However, the string was held up on the bottom of the top casing stub at 220m. It was concluded that at least one of the section-mill's knives was not fully retracted due to the swarf was accumulated inside the section mill's knife slots while the knives were expanded and disabled the knives to retract. Furthermore, the string was rotated with higher radial speed of 120 RPM, higher flowrate of 430 GPM and higher stand-pipe pressure of 1750 psi while being reciprocated up and down. After 12 hours, section-mill's knives were finally retracted to its housing. The well was circulated clean again by using high viscosity pill for twice bottom-ups until no swarf was found on surface and proceeded with pulling out of hole to surface. A dedicated 8.5" clean out run by using string magnet BHA was run with parameter: 30 RPM/ 387 GPM/ 1100 psi/ 2klb-ft torque. This was to ensure well was free from debris prior to continue the following P&A programs.

3 Conventional Section Mill's Challenges

The section-milling experience from well X by using conventional technology concluded that the main challenges derived from the swarf (milling debris). Swarf is an unavoidable by-product of section milling operation. A conventional milling of 15 m of 9-5/8" casing 53.5 lb/ft approximately generated 3,000 pounds of sharp metal cuttings and that must be circulated back to surface; through the BOP, flowlines, and shaker systems. Most complication came from the swarf build-up. Even though, hole cleaning analysis had been carried according to industrial requirement with parameter: 310 GPM/ 60 RPM to reach 150 ft/min annular velocity. In actual operation, 387 GPM and 65 RPM were used, however it still resulted in insufficient hole cleaning.

Excessive metal cuttings pose 3 main challenges to the operation such as:

1. The swarf deposit, which was turbulent inside the well, increased the mechanical stuck pipe likelihood. In fact, based on the section-milling operation at well X, 42 hours was spent just to free the string from the stuck pipe event and additional 24 hours for dedicated clean out trip was performed to ensure no swarf deposit is present downhole.
2. Retrieving and handling the swarf are not only consumed time and resources / cost but also posed additional health, safety, and environmental (HSE) risks to the personnel.
3. The Rate of Penetration (ROP) during milling operation was limited by debris removal capacities (lb/min) on surface. Because of excessive swarf return on surface, operator need to limit the mill's ROP to match with the swarf handling unit capability on surface.

All of the challenges led to additional time, cost, personnel, and risk to the operation. These challenges drove Company and Baker Hughes to deploy a cutting-edge swarf-less section mill technology, which left all swarf in the wellbore while performing section milling. This system provided a faster, safer, more reliable, and more economical solution to do a section milling without the consequences of circulating swarf to surface.

4 Upward Swarf-less Section Mill System Overview

Upward swarf-free section milling system provided a reliable solution for section-milling without the negative side effects that is swarf[2]. With its innovative upward direction section mill using left hand motor and auger assembly, the technology eliminated all swarf completely, and ultimately enabled the well to have a secure rock-to rock barrier. The complete system's bottom hole assembly will be discussed individually and could be seen as follows:

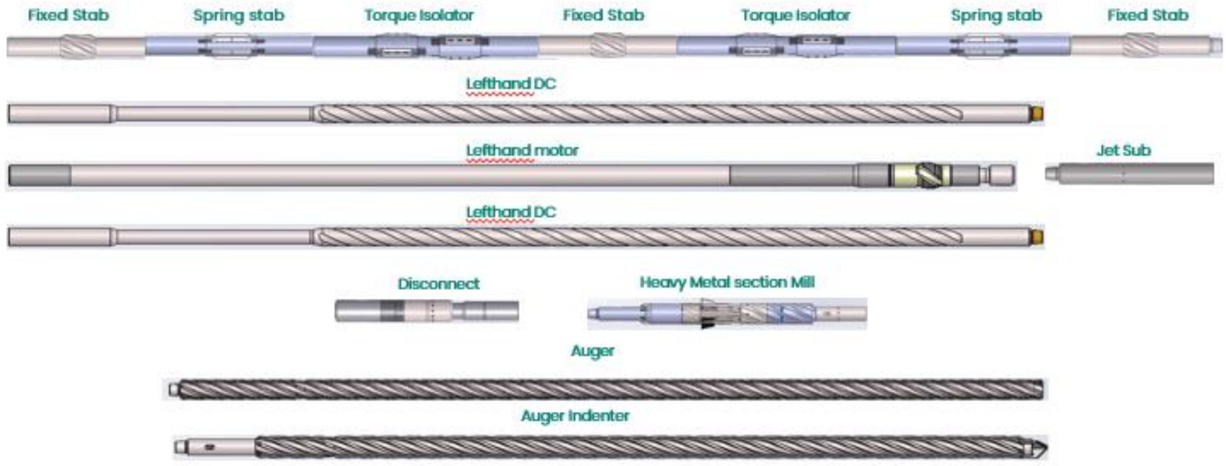

Figure 1. Upward Swarf-less Section Mill System BHA

Auger

The auger is specifically designed to force all cuttings down the rathole and limit the lifting of the swarf. It is comprised of two parts: the auger and auger indenter. Together, these parts circulate down metal cutting below the section milling's window to deposit all cuttings into the rathole. Because the cutting does not have to be circulated to surface, there is no need to change over to a high viscosity milling fluid, saving additional cost and logistics.

Upward swarf-less Section Mill

Upward swarf-less section mill is a hydraulically operated upward section mill, which cuts from the bottom of window and mills in upward direction to mechanically transport and allow all metal cuttings deposited down below the cut-out depth. Moreover, this system uses advanced milling technology carbide cutting structures knives to provide more optimal milling ability.

Emergency Disconnect

The emergency disconnect is a tension activated disconnect tool that utilizes a single large tensile stud. This allows for the emergency disconnect to be able to handle the tensile and torque of the milling operation, while still being able to disconnect by overpull in the event of a stuck BHA.

Jet Sub

Jet sub is a solid sub with eight interchangeable nozzles to fit any section milling operation. These nozzles divert flow above the section mill to regulate piston's pressure and help keep cuttings in the hole.

Left-Hand Motor

The left hand motor provides downhole left hand rotation and torque to the section mill and auger below it. Unique left-hand rotation is needed to prevent unthreading casing coupling while milling upwards.

Spring Stabilizer

The spring-activated stabilizer is designed to help centralize the section milling system and maximize operational efficiency. It has pads that are pushed out by springs in order to contact the casing. This contact provides centralization to improve the performance of the section mill and torque isolator tools.

Torque Isolator

Torque isolator is a hydraulically operated tool that allows for axial movement while prohibiting rotational movement by use of hardened steel wheels. These wheels anchor into the casing to isolate the reactive torque from motor during milling operations, while maintaining the ability to roll and move axially.

5 Upward Swarf-less Section Milling Case History

Upward swarf-less section milling was performed on well Y to mill 15m section of 9-5/8" 40 lb/ft casing. After conducting a surface test, the BHA was tripped in hole to perform the cut out at depth 655m. The string was pumped with 294 GPM and 1900 psi without any rotation After several minutes, a 200 psi pressure drop was observed at surface, confirming the cut out was successfully made.

Following the cut out, 5,000 – 10,000 lbs over-pull weight was applied on the bottom of the top casing stub and thus upward section-milling operation was continued with average rate of penetration of 1.5m/hr while maintaining parameter: 294 GPM/ 1900 psi/0 RPM/ 5-10 klbs over-pull. The swarf was not observed on surface. After reaching target-milling depth of 640 m, reaming operation was performed between milled window intervals (640-655 m) to ensure all swarf was deposited below bottom window. Then bottom hole assembly was pulled out of hole. On surface, the section mill knives were approximately 25% worn after milling through 15 m of casing. After the 9-5/8" upward swarf-less section mill was completed, an inflatable plug across the section-milled depth was successfully set without encountering any issue. The operation was proceeded with putting cement column and eliminating sustained casing pressure.

Total milling time for the job was 10 hours or a 1.5 meter per hour rate of penetration. The upward section milling operation eliminated non-productive operating time (NPT) and demonstrated the ruggedness and reliability of new upward swarf-less section milling.

6 Result

From the successful upward swarf-less section mill deployment in well Y, there are multiple benefits, which were perceived directly such as:

1. **Saved 3.5 days for Section Milling operation**
   The new section mill proved to be a robust technology, which eliminates non-productive time while doing the operation. Table 1 below compared duration needed to perform section milling between using conventional and upward swarf-less technology based on experience on well X and Y.

Table 1. *Section Milling Time Comparison: Conventional vs Upward Swarf-less*

No	Job Step	Duration (Hrs)	
		Duration Conventional Section Milling	**Duration Upward Swarf-less Section Milling**
1	Make up BHA	5	7.5
2	RIH to 650 m	6	6
3	Section mill 15m	65	11
4	Circulate Hole clean	12	0
5	POOH	6	6
6	Clean out Run + BOP Jetting	23	0
7	Break BHA	4	7
Total Duration		**121**	**37.5**

From Table 1 above, it can be seen that upward swarf-less section mill saved 83.5 hours or 3.5 rig days time. This was due to several factors such as: 50% faster rate of penetration (1.5m/hr vs 0.75m/hr), no stuck event during the whole operation and no dedicated clean out run needed. This also led to cost savings realized by faster and more efficient operation executed with upward swarf-less section mill. Furthermore, additional cost reduction also realized by elimination of milling fluid, swarf handling equipment, and sward disposal cost, which was previously required if utilizing conventional technology. Below is the formula of potential cost reduction[1]:

Total Cost reduction = Operation Cost saving from faster operation + Milling fluid cost + swarf handling unit and crew cost + swarf's transport and disposal cost

Although higher investment needed to deploy this new technology, the saving combination from time, equipment, personnel, materials, and service thru upward swarf-less section mill usage contributed to overall cost reduction from the operation.

2. **No Swarf (milled casing debris) at all to surface**
   From upward swarf-less section mill experienced in well Y, it was proven that this new technology successfully deposited all Swarf to the rat hole. Thus the overall operation's health, safety, and environmental risk are greatly reduced by eliminating manual cleaning of surface equipment (shale shaker, pits, flow lines, etc), eliminating risk of damaging surface equipment (no swarf circulated to BOP, mud pump, etc), and eliminating the requirement to dispose tons of swarf, milling fluid's solid.

3. **Closer to Net Zero and Saved 4.6 tons of CO_2 Emission**
   Carbon emissions reduction is one of the main focus for Company and Baker Hughes to achieve net-zero emissions to support environmental sustainability. From 84 hours faster P&A operation in well Y, Company and Baker Hughes have contributed to save 4.6 tons of CO_2 Emission. Calculation methods for carbon emission are based on API Compendium (2009)[4] as per below:

E_{CO2} = FC X D X Wt%C X 44/12

Note:

E_{CO2}: Carbon Emission

FC : Fuel consumption in Gallon

D : Diesel density (7.07 ppg)

Wt%C : Carbon content on diesel (86.34%)

FC = ER x LF x OT x ETT x 1/HV

Note:

ER : Rating of equipment (HP)

OT: Operating time (Hr)
ETT : Equipment thermal efficiency (Diesel = 8,089 Btu/HP-Hr)
HV : Heating Value ($5.83x10^6$ Btu/gal)

Using formula above, then carbon emission saving can be summarize as per below:

Table 2. Carbon Emission Saving Calculation

Equipment	Rating (HP)	Saving Time (hr)	Fuel Saved (gal)	Saved CO_2 Emission (Ton)
Rig	750	83.5	87.4	0.97
2 Mud Pumps	1100		231.7	2.59
Generator set for Accommodation	770		89.2	1
Total CO_2 Emission Saving				**4.6**

7 Conclusion

Section milling is a conventional method for casing removal during plug and abandonment (P&A) operations where annular well integrity is compromised or questioned. The removal of casing by milling a window re-opened access to the formation, enabling placement of a rock-to-rock barrier. However, the conventional section mill posed a serious challenge from tons of swarf retrieval, which significantly increased the operation's time, cost, and HSE risk. To address these challenges, a new swarf-less section mill needed to be deployed to execute the operation

Upward swarf-less section milling provide a reliable solution for section milling without the negative side effects of swarf. With its Innovative upward direction section mill using left hand motor and auger assembly, the technology eliminates all swarf to surface, while still enabling a secure rock-to rock barrier.

This first successful upward swarf-less section mill deployment in Asia Pacific proved value of this new technology, which saved 3.5 days rig time and reduced 4.6 tons of CO_2 emission. By leaving swarf in rat hole, section milling operation is faster, safer, more reliable, and less impact to the environment. Thus, upward swarf-less section-mill is a solution for better future section-milling operation.

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