

First Time in Indonesia, CTU Clean Out Totally Plugged Scale : Risks, Mitigations, and Lessons Learned

Redha Bhawika Putra, Tommy Souvanir, Paulus Panggabean, and Edyson Purba, Star Energy Geothermal; Haleyna Arstianti and Agus Cahyono, BHGE

Star Energy Geothermal and BHGE

Keywords

Coiled Tubing Unit (CTU), clean-out, scale, rotary jetting, milling, workover

ABSTRACT

AWI A-4 is an important well at Salak Geothermal Field, Indonesia because it impacts the quality of produced steam of its surrounding wells. In 2015, an unsuccessful workover to clean-out scale resulted in scale totally plugging the wellbore. With the well plugged by scale, the 2017 AWI A-4 workover planned to mill the scale initially and complete the scale clean-out with the Roto-JetTM tool. A major challenge facing this type of workover operation is that the CTU string is not stiff and not designed for milling (pushing, and rotating). Another challenge was that the calculated impact pressure of the CTU-conveyed Roto-JetTM is less than the required pressure to overcome the hydrostatic pressure of full column of water. Nevertheless, Star Energy Geothermal (SEG) and Baker Hughes General Electric (BHGE) attempted to mill and clean-out the scale using the CTU.

The initial attempt to mill the scale plug was unsuccessful as problems with the surface filter resulted in the CT string getting stuck. In view of this setback, SEG and BHGE optimized the Roto-JetTM tool configuration to increase both the pumping rate and impact pressure. The second attempt with the Roto-JetTM tool successfully removed the scale plug resulting in an increase in steam production of surrounding wells equivalent to about 6.5 MW. This scale plug clean-out using the CTU is the first successful experience in the Indonesian geothermal industry.

1. Introduction

The Salak Geothermal Field is located near Bogor City, West Java Province, Indonesia. It is a hot water-dominated geothermal resource operated by Star Energy Geothermal (SEG) with a total installed capacity of 377 MW (Figure 1). Steam comes from production wells completed to about 5,500' - 10,000' Measured Depth (MD).

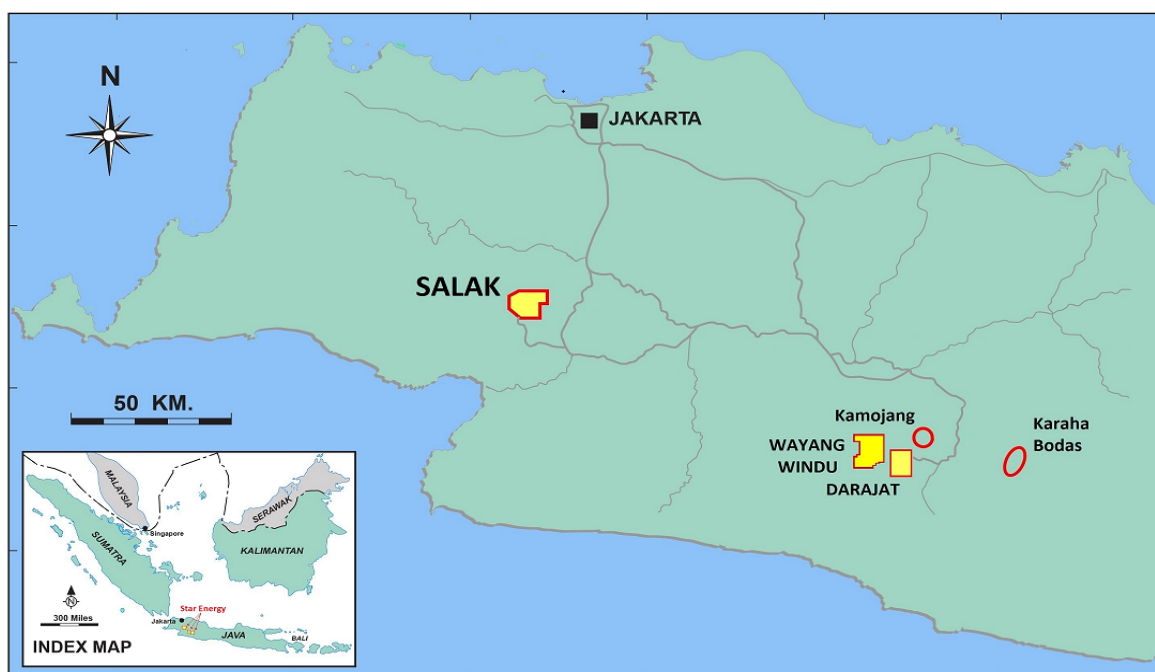


Figure 1: Map showing the location of the geothermal fields operated by Star Energy Geothermal, namely, Salak, Wayang Windu and Darajat. Also shown are the other geothermal fields in this geothermal province in West Java, Indonesia.

AWI A-4 is a unique well at Salak Field as it has the highest Non-Condensable Gas (NCG) content (>10 wt.%) among all production wells. This well has to be bled using the 3" side valve to discharge its NCG and enable the surrounding wells to produce optimally (Salak Asset Management Team, 2017). During an initial attempt to clean-out scale in this well in 2015 using the Roto-JetTM, the planned workover totally plugged the wellbore at 3,100' MD and resulted in mud return to the surface. As the workover operation then did not have a return tank it was decided to stop the operation and avoid any fluid spills. This unsuccessful workover resulted to the continued accumulation of NCG in AWI A-4 and steam production from surrounding wells was reduced.

Cleaning out scale with Coiled Tubing Unit (CTU) is a common operation for Salak Geothermal Field and Darajat Geothermal Field (another asset operated by SEG). With a rotary jetting tool (called Roto-JetTM) owned by Baker Hughes General Electric (BHGE), several success campaigns have been executed. This tool provides hydraulic power to remove scale in the wellbore. Compared with Work Over Rig, CTU with Roto-JetTM is preferred because (1) the scale clean-out can be conducted faster due to the absence of connecting drill pipes (2) faster mobilization time due to fewer number of equipment loads (3) the ability of Roto-JetTM to clean the perforated liner with rotary jetting (which a rig cannot accomplish). However, the CTU with Roto-JetTM has never been used to clean-out a totally plugged wellbore with scale at Salak, Darajat, and elsewhere in Indonesia. A primary reason for this is that theoretical estimations indicate that the calculated impact pressure from the Roto-JetTM was lower than the calculated hydrostatic pressure resulting from the column of water inside the wellbore and the required impact pressure to clean the scale itself; thus, it was perceived that the Roto-JetTM tool will not work in this situation.

In Work Over Campaign 2017, in order to clean out the totally plugged scale at AWI A-4, the Workover Team initially executed milling operation with milling tool. Based on BHGE reports, it was the first experience in Indonesian geothermal industry since CTU has never milled a totally plugged scale in big hole (inside 10-3/4" liner) which require high annular velocity to lift the scale cuttings and avoiding stuck pipe. Despite the comprehensive preparation, Workover Team failed this operation due to problem with surface filter and stuck pipe. However, after further discussion, Workover Team and BHGE Team came up with the optimization of Roto-Jet tool which results in higher impact pressure and successfully cleaned out the totally plugged scale.

2. AWI A-4 History

2.1 AWI A-4 Before 2015

AWI A-4 was initially drilled in 1996 as production well with big hole completion (i.e., 10-3/4" production liner) (Drilling Team, 2003). It was re-drilled in 1997 and successfully put online with initial production of 200 kilo-pounds per hour (kph) of steam and 800 kph of brine. The well was re-drilled again in 2003 (see Figure 2 for well schematic) but was not produced to the system which resulted to a significant increase in NCG inside its wellbore (i.e., 10-11 wt.%). AWI A-4 was eventually put on bleed through the 3" side valve to keep discharging its NCG. Subsequent analyses indicated that this well has the strongest connection with surrounding wells such that shutting in AWI A-4 will result to a significant increase in NCG of its neighboring wells and surpass the capacity of the Gas Removal System (GRS) of the power plants (Salak Asset Management Team, 2017).

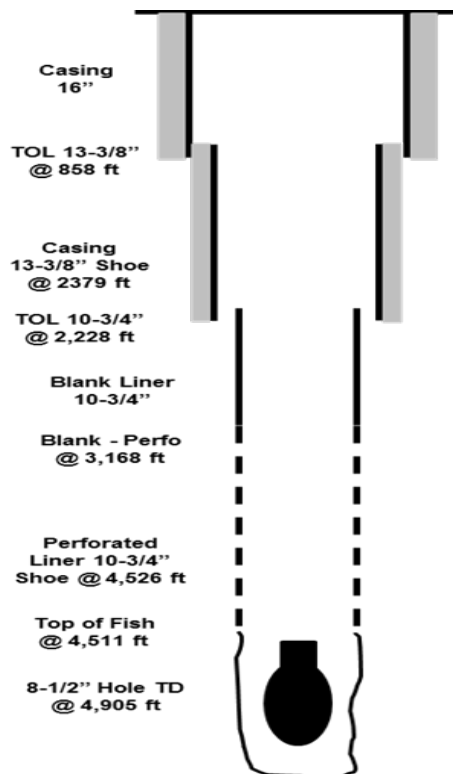


Figure 2: Schematic diagram showing the completion of AWI A-4.

Downhole logging surveys in 2014 showed scale deposition inside the AWI A-4 wellbore resulting to less NCG bled to the sump, and consequently increasing the NCG production of surrounding wells (Workover Team, 2015). Analysis of the scale indicated that it consists mostly of hard and brittle quartz located at depth 3,082' – 3,187' MD (or the transition between the 10- $\frac{3}{4}$ " blank and 10- $\frac{3}{4}$ " perforated liners). A snapshot of the scale using the Down Hole Video (DHV) is shown in Figure 3.



Figure 3: Snapshot of scale inside AWI A-4 from the Down Hole Video (DHV).

2.2 2015 Workover

Cleaning out the scale at AWI A-4 was initially attempted during the 2015 Salak Workover Campaign (Workover Team, 2015). This workover project utilized the CTU with Roto-JetTM tool.

The AWI A-4 scale clean-out spudded on December 28, 2015. After the well killing process, the Roto-JetTM tool was lowered into the wellbore and started cleaning scale from near surface down the wellbore while pumping power plant condensate at the backside to maintain vacuum pressure. An obstruction was tagged 2,432' MD and the Roto-JetTM tool was pulled back above the obstruction by a few feet (to prevent it from getting stuck) before going down slowly to penetrate the obstruction. While attempting to tag the obstruction again, the Well Head Pressure (WHP) suddenly increased to 500 psig (usually it is negative due to vacuum pressure) indicating that pressure was building up inside the wellbore. It was believed that scale cleaned by the Roto-JetTM from near surface to the obstruction has plugged the wellbore and resulted to the build-up of a water column and positive WHP at the surface (Workover Team, 2015). The scale clean-out at AWI A-4 was aborted because the existing workover equipment was not ready for modification to take returns from the plugged wellbore. No condensate spill is allowed in Salak Geothermal Field.

With the unsuccessful scale clean-out in 2015 and importance of AWI A-4 in maintaining the production of low NCG steam, this well was again included in the 2017 Salak Workover Campaign. This time, milling and “roto-jetting” were planned to clean the plugged wellbore and these will be explained in detail in the following sections.

3. CTU Equipment for 2017 AWI A-4 Workover

Both milling and Roto-Jetting operation to clean at AWI A-4 was designed to use the same surface equipment. The difference would be with the bottom hole assembly.

3.1 Surface Equipment

3.1.1 String, Injector, and BOP

It is common in geothermal operation to use bigger size of Coiled Tubing String compare to oil and gas operation. BHGE use both 2" and 2-3/8" CT string for geothermal operation. In this particular operation at AWI A-4, 2-3/8" CT was used since it has more pumping capacity to provide more annular velocity and also has more pulling capacity to enable it to get freed in case it gets stuck. The detail data of string, injector, and BOP used for both milling and Roto-Jetting operation at AWI A-4 is shown in the Table 1.

Coiled Tubing OD	2.375 in
Coiled Tubing Wall Thickness	0.19 in
Coiled Tubing Weight	4.4 lb/ft
Coiled Tubing Length	4500 ft
Coiled Tubing Yield Strength	90,000 psi
Coiled Tubing Torque Yield	5,438 ft-lb
Injector Capacity	80000 lbs
BOP ID	4.06 in
BOP Pressure Rating	10,000 psi
BOP Component	- Shear/Seal Ram - Pipe/Slip Ram - Pipe Ram - Flow Cross

Table 1: Coiled Tubing Unit Specification

3.1.2 Water Injection System and Other Surface Equipment

In general, three lines and pumping systems are required during well clean out operation with Coiled Tubing. The first line (i.e., string line) is a high pressure line which goes to the CT string. The second (i.e., killing line) is another high pressure line for any killing operation and goes to backside valve. The third (i.e., quenching line) is a low pressure line to maintain the vacuum condition during CTU operations. The first line used two surface filter, one close to the pump and another close to the CT string to avoid impurities reaching and affecting to BHA.

In CTU operations, it is desired to have another well control barrier in addition to the Blow Out Preventer (BOP). A CTU operation always starts with the well killing well process which aims to cool down the well and create vacuum (or negative) pressure. As it was expected that full circulation returns will be obtained during the scale clean-out at AWI A-4, the kill and quenching

lines were installed to ensure readiness in mitigating any trapped steam/pressure below the scale totally plugging the wellbore after milling and/or roto-jetting successfully remove it.

Up to 30 bpm (depend on the well requirement) of condensate water were provided by Production Team for this operation and flowed to the Tank 1 (400 bbls capacity) which then went to three available lines mentioned above. Tank 2, another 400 bbls capacity water tank, took return from the well and flowed it back to Tank 1 if the return quality is still good/clean.

Since friction reducer is used to enable pumping more fluid without exceeding the limit pumping pressure and gelling agent is used to increase lifting capacity, a mixing tank was also prepared. Please see Figure 4 for the schematic of the Water Injection Line for the AWI A-4 scale clean out.

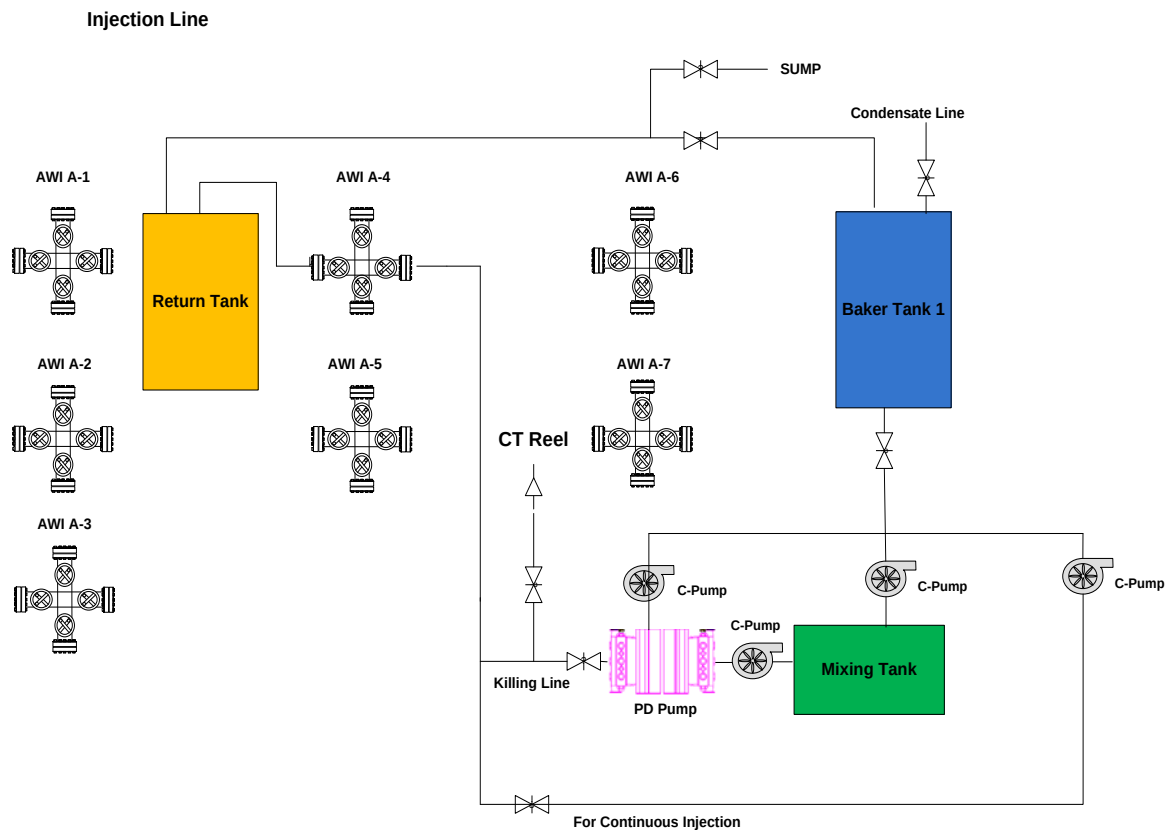


Figure 4: Schematic diagram showing the water injection set-up for the AWI A-4 Workover using the CTU.

3.2 Bottom Hole Assembly

3.2.1 Milling BHA

The BHA for milling the scale consists of the CT connector, double flapper check valve, $\frac{3}{4}$ " ball circulation sub, $\frac{7}{8}$ " ball disconnect tool, hydraulic centralizer, motor, and the actual mill. The double flapper check valve blocks any liquid that will go back to the string. The circulation sub will be used during stuck condition where additional fluid is required to lubricate the BHA. The

disconnect tool allows the string to be disconnected from the BHA if required during stuck condition. Both the circulation sub and disconnect tool require a steel ball to be activated. The hydraulic centralizer is able to expand up to 9-7/8" to reduce the possibility of the milling tool damaging/milling the casing. Specifications of the motor are shown in Table 2. A tapered mill was considered as it has teeth at both its top and bottom for milling the scale downside and upside just in case it gets trapped/stuck.

Dimensions, Connections		
	US Units	SI Units
Tool OD	2-7/8 in.	73.0
Length	12.60 ft	3.84 m
Weight	200 lb	90 kg
Top Connection	2-3/8" PAC DSI	
Mill Connection	2-3/8" PAC DSI	
Bearing Type	Fluid Lubricated	
Performance Data		
Lobe Configuration	5/6	
Number of Stages	4.0	
Flow Rate	40-120 gpm	150-450 lpm
Speed	115-345 rpm	
Operating Differential Pressure	1,160 psi	80 bar
Operating Torque	885 ft-lb	1,200 Nm
Operating Power Output	58 hp	43 kW
Maximum Differential Pressure	1,450 psi	100 bar
Maximum Torque	1,105 ft-lb	1,500 Nm
Operational Data		
Operating WOB	4,720 lb	21 kN
Maximum WOB	7,200 lb	32 kN
Maximum Overpull	90,000 lb	400 kN
Fluid Type Limit	No general limitations, in case of uncommon fluid systems a compatibility test is recommended	
Maximum Temperature (D Stator)	320°F	160°C
Maximum Temperature (F Stator)	374°F	190°C
Maximum Temperature (K Stator)	392°F	200°C
Maximum Sand Content	1%	

Table 2: Motor Specification

Except for the mill, which has a 4-1/2" outside diameter (OD), the all the other BHA components have 2-7/8" OD. The complete specifications of the Milling BHA is shown in Figure 5 while the tapered mill is shown in Figure 6.

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Figure 5: Details of the Milling BHA for the AWI A-4 Scale Clean-out.



Figure 6: Photos of the tapered mill used at AWI A-4

3.2.2 Roto-Jet BHA

The BHA for roto-jetting consists of the CT connector, double flapper check valve, $\frac{3}{4}$ " ball circulation sub, $\frac{7}{8}$ " ball disconnect tool, down hole filter, Roto-JetTM motor, and nozzle. The nozzle is covered by a 4" housing and rest of the BHA components has a 2- $\frac{7}{8}$ " OD. The roto-jetting BHA has a downhole filter because the Roto-JetTM tool is sensitive to tiny particles pass through the surface filter. The remaining parts have the same function with the milling BHA. The Roto-JetTM tool has a turbine inside which rotates the tool when liquid flows inside the tool (Figure 7). Figure 8 shows the Roto-JetTM BHA used at AWI A-4.

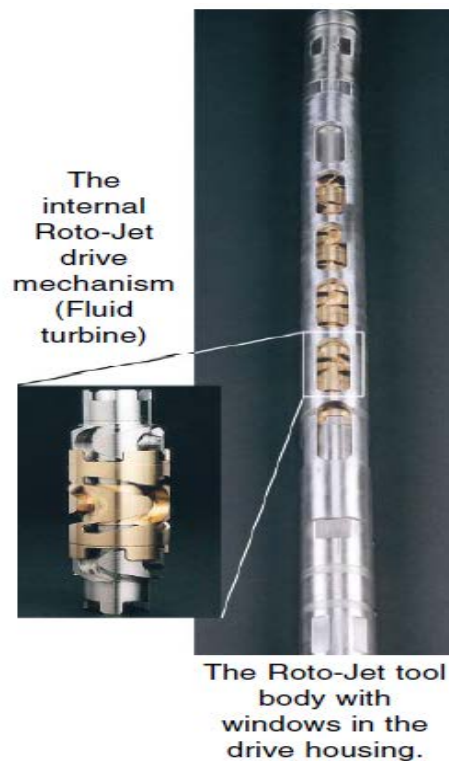


Figure 7: Photo showing the RotojetTM turbine (from BJ Services, 2002).

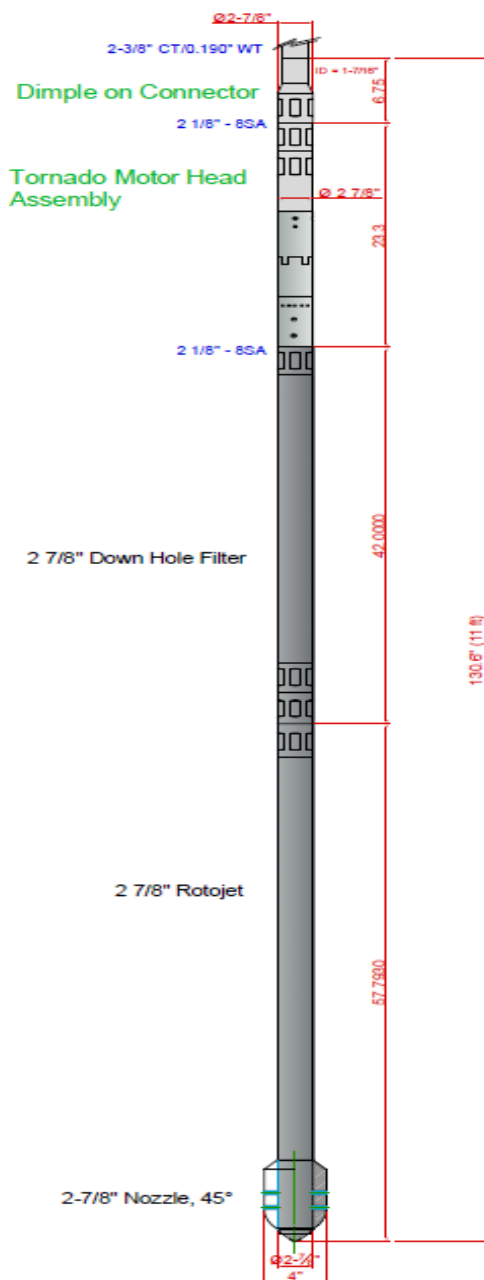


Figure 8: Rotojet™ BHA for the AWI A-4 scale clean-out.

Normally, two types of jetting nozzle are utilized to clean-out scale in wells. The first jetting nozzle is the 45° Roto-Jet™ which will be run first to clear access to the wellbore; the second

jetting nozzle is the 90° Roto-Jet™ which aims to clean the holes in the perforated production liner. Figure 9 shows these two types of jetting nozzles.

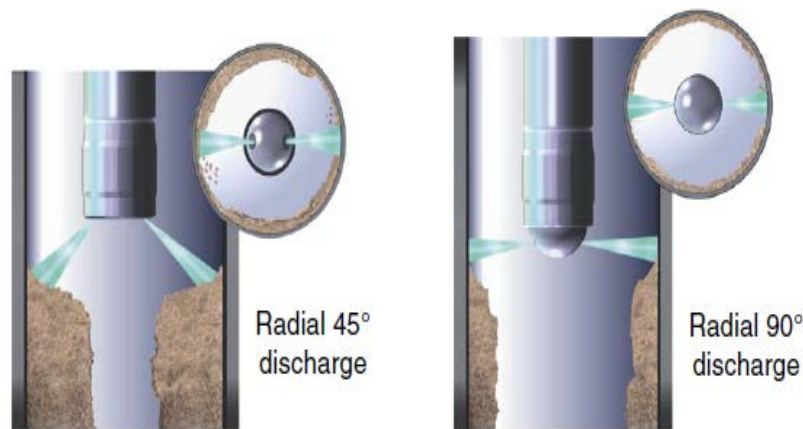


Figure 9: Schematics showing the 45° and 90° mechanical jetting nozzles of the Rotojet™ Tool (from BJ Services, 2002).

4. Milling Totally Plugged Scale at AWI A-4

Successful milling operations to clean-out scale inside wellbores using the CTU have been conducted by SEG at both Darajat and Wayang Windu Geothermal Fields. However, SEG has not experienced milling scale that has totally plugged a wellbore.

The 2017 AWI A-4 workover was designed to first mill the scale plugging the wellbore using a CTU-conveyed milling tool, and then clean the rest of the wellbore with the Roto-Jet™ tool. This was the first time in the Indonesian geothermal industry that the CTU will be used to mill a wellbore totally plugged with scale. BHGE reported that the CTU has not been used to mill a big hole wellbore totally plugged with scale (i.e., inside the 10-3/4" production liner) as it was estimated that a high annular velocity is required to lift the scale cuttings and avoid getting stuck inside the liner.

4.1 Planning

Several concerns (including risks and their mitigation) were evaluated during the planning of running the CTU-conveyed milling tool. Some of these concerns include the expected reactive torque which may cause the CTU to buckle, possibility of milling the casing, inadequate push capacity and torque provided by the CTU and the motor, and the potential of the BHA getting stuck and buried by residual scale.

The first concern about potential buckling because of reactive torque from the milling operation can be resolved by comparing the torsional yield capacity of the CT string and the stall torque of the milling motor. The CT string has a torsional yield of 5,438 ft-lbs while the stall torque of the milling motor that will be used was 935 ft-lbs. From these numbers, the motor will not be able to buckle the CT string. In addition, the BHA make up torque is only 2,300 ft-lbs.

Since the CT string is not a straight stiff material, there was concern that the milling tool may potentially mill the casing and not just the scale and jeopardize wellbore integrity. However, the

24.5' length of the milling BHA results in $<1^\circ$ for the milling tool to mill the casing, make it not an ideal condition for milling. In addition, centralizers were installed to enable the tool to stay at the middle of the wellbore as much as possible. A diagram based on simulation to visualize this situation is shown in Figure 10.

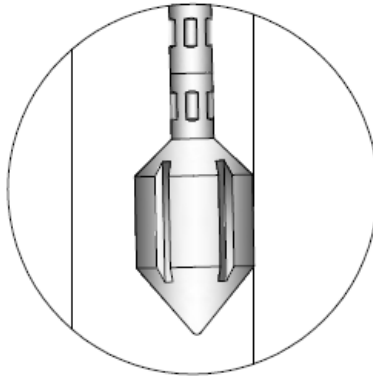


Figure 10: Schematic showing the location of the milling tool inside the wellbore.

Another challenge posed by using the CTU with no straight stiff material is the concern that the tool has adequate push capacity required to mill the scale considering the buoyancy provided by liquid column inside the wellbore. Experience from previous scale milling operations indicate that the required push capacity should be 1,000 – 1,500 lbs at the bottom. Simulation suggests that ~5,000 lbs can be provided at about 4,000' MD by the CTU; this push capacity is more than three times the estimated requirement.

With respect to the motor, the concern was whether the motor can provide enough torque to mill the scale. Boedraux and Falk (2005) documented cleaning barium sulfate scale (which is harder than quartz silica) with a 2- $\frac{1}{8}$ " motor and a stall torque of 375 ft-lbs only. The AWI A-4 workover planned to use a 2- $\frac{7}{8}$ " motor which has a bigger stall torque of 935 ft-lbs. Since the torque cannot be measured in the surface, the workover team estimated it by defining the maximum differential pressure between "on-bottom pressure" and "off-bottom pressure." Analysis suggested that the calculated maximum differential pressure is 1,100 psi to not exceed stall torque.

To avoid the tool getting stuck by scale debris, a gel additive would be pumped to increase the lifting capacity of the circulating fluid. Simulation indicated that 3.4 BPM will be able to lift the scale cuttings up to the surface within 120 minutes; this was more than enough since the initial objective was to lift the scale cuttings just above the milling BHA (top of the cleaned casing).

4.2 Execution

On September 11, 2017, the first attempt to clean-out the totally plugged wellbore commenced by filling up the well with condensate and measuring the loss rate. The estimated loss rate was 0.5 BPM; this loss rate is an important parameter to determine if the scale plugging the well has been broken. It is expected that scale debris/cuttings will fall down and bury the BHA (stuck)

once the scale plug is broken. As the loss rate increases, the BHA will be pulled back to a safe depth.

The 4.5" milling tool with CT was run with initial pumping of 1 BPM (to mitigate the collapse of CT string). The tool tagged the obstruction at depth 3,105' MD. The milling tool was pulled back (raised) and the pumping rate was increased to 3.5 BPM to define the "off-bottom pressure." As planned, the difference between the on- and off-bottom pressures shall less than 1,100 psi. Subsequently, the scale was milled from 3,105' – 3,125' MD at 3 – 5 feet per minute while keep pumping 3.5 BPM. As the pump rate was fixed, the on-bottom pressure mainly depended on the weight-on-bit (WOB). Thus, the difference between the on- and off-bottom pressures was carefully monitored and maintained at less than 1,100 psi during the milling operation.

At 3,125' MD, the surface filter installed to help the downhole filter to block debris entering the motor was plugged. To enable cleaning of the surface filter, the milling tool was raised to 3,070' MD and pumping through the CT string was stopped. Unexpectedly, it was observed that scale debris and the gel have formed a mud cake at the surface filter. After cleaning the surface filter, the milling tool was lowered down to 3,125' MD to continue milling. Unfortunately, the pump pressure suddenly increases and over pull was experienced at 3,131' MD as the CT string got stuck. The milling BHA was eventually freed and pulled out of hole after several hours of dislodging it. Inspection showed that there was no metal scratches on the milling tool confirming that the blockage was scale and not a collapsed casing.

Analysis indicated that the CT string got stuck when pumping was stopped when the surface filter got blocked and scale debris settled and probably gathered around the milling BHA. The perceived solution to this problem in future operations is to install an additional/backup line including a surface filter (in parallel) that can be used anytime something happens to the first surface filter.

5. Roto-Jetting Totally Plugged Scale at AWI A-4

As the first attempt failed, the second attempt to clean out the totally plugged scale at AWI A-4 was conducted with Roto-Jet tool.

5.1 Planning

The Roto-JetTM tool removes scale through the combination of erosion and stress cycling. Erosion is when the fluid strikes the scale and stress cycling is when pressure is applied on and off as the jet is rotating (Campbell and Brunskill, 2000). This tool uses plain water as the medium to transfer the energy.

Previous Roto-JetTM experience at Salak Field was always in a "loss" condition, i.e., no liquid column builds up in the wellbore. In a loss condition, the impact pressure provided by the jetting nozzle to clean the scale is not encountered by the hydrostatic pressure of the liquid level. At AWI A-4 (which had a liquid column because scale is totally plugging the wellbore), the calculated roto-jetting impact pressure was less than the required impact pressure to both clean the scale and encounter the hydrostatic liquid pressure. The Workover Team discussed with the BHGE some optimization on the Roto-JetTM to increase its impact pressure.

It is known that increasing pumping flow rate through the CT string will not only increase impact pressure but also increase pumping pressure and pressure inside the string. Considering the safety factor, the CT string can only withstand 5,000 psi during static condition and 4,000 psi during dynamic condition. To increase the pumping flow rate, the use of a friction reducer was agreed.

Furthermore, it was determined that the configuration of the Roto-JetTM tool can be optimized, namely, type of nozzle and number of turbines, magnets, and bypass ports. Changes on these parameters will impact both the Roto-JetTM RPM and CT impact pressure.

All of the flow inside the CT string will eventually go to the jetting nozzles. Before the nozzles, the fluid flow is separated into two directions. One goes to the turbine to rotate the Roto-JetTM while another is bypassed directly to the jetting nozzles. Increasing the number of bypass ports means increasing the allocation of fluid flow to the jetting nozzles which would eventually reduce the CT pressure. With this configuration and at the same flow rate, lower CT impact pressure will be obtained.

Another constraint on this modification is the rotation speed of the Roto-JetTM. To clean-out the scale effectively, the optimum speed should be in the range of 300 – 600 rpm. Too slow or too fast rotation speed is not desired since it will not provide enough time between application and re-application of pressure (i.e., stress cycling) to take place on the scale (Campbell and Brunskill, 2000). Figure 11 shows the effectiveness of roto-jetting vs. the rotation speed. Therefore, any modification in the Roto-JetTM should also target a rotation speed of 300 – 600 rpm.

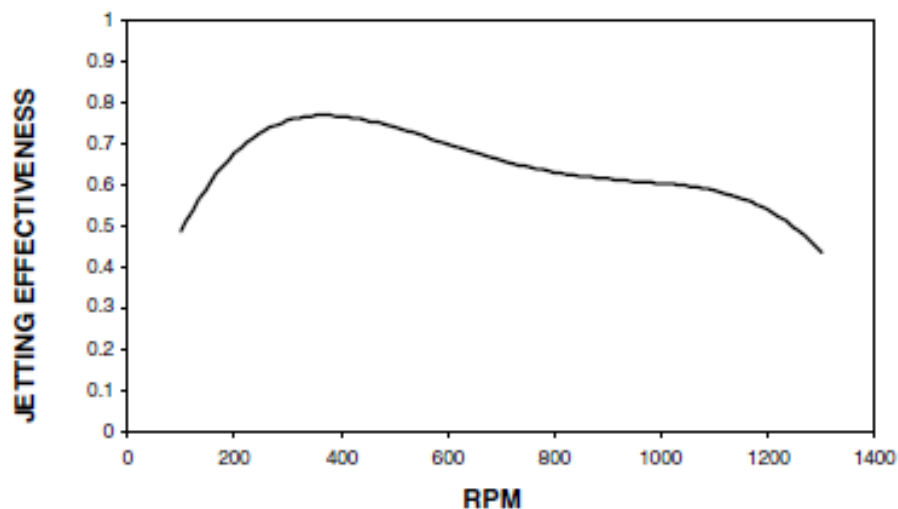


Figure 11: Chart showing rotojetting effectiveness vs. RPM (Campbell and Brunskill, 2000). Note the decline in effectiveness at about 400 RPM.

Modification of the number of bypass ports and turbines (based on simulation) enabled pumping 4.2 BPM (instead of 3.5 BPM) while maintaining the CT pressure at its static and dynamic condition. The estimated impact pressure with this increased flow rate was ~1,488 psi (compared to 1,026 psi at 3.5 BPM). This calculated impact pressure is already taking into account the full column of liquid level and is higher than required impact pressure for the scale sample. The scale sample has Mohs scale 2 and, based on simulation software, require 862 psi assuming that the

scale is “homogenous” and has no cracks. All planning condition was simulated with BHGE coiled tubing software, CIRCA™.

As opposed to the previous well clean-out operation, the objective for this operation was just to break the plug, not to clean the wellbore all the way down.

5.2 Execution

The second attempt to clean-out the scale plug was conducted on October 17, 2017. After estimating the loss rate, the Rotojet™ tool was lowered to the obstruction depth while pumping 1 BPM. At 3,030' MD, the flow rate was increased to 4.2 BPM. The tool went down slowly at about 1 – 3 feet per minute while maintaining stable slack weight of ~13,000 lbs; a pull test was conducted every 20' of progress.

While cleaning out scale at 3,142' MD, circulation return to the surface stopped, indicating that the scale plug was already broken and the pumped fluid had access downhole. The WHP reached vacuum to -7.5 psi while pumping 10 BPM indicating that a loss condition was obtained. As planned, the Roto-Jet™ tool was raised to a safe depth above where the plug was breached to avoid getting stuck. After monitoring the behavior of the well for a period of time, the tool was then raised to surface and the operation was successfully finished.

5.3 Scale Clean Out Results

Removal of the scale plug which totally blocked the wellbore allowed venting of the NCG at AWI A-4 to the diffuser sump. Post-workover evaluation indicates that production from surrounding wells increased by about 105 kph (~6.5 MW) after scale was cleaned out at AWI A-4.

6. Conclusion

Star Energy successfully cleaned out the scale totally plugging AWI A-4 after looking back at the unsuccessful initial attempt in 2015, applying lessons learned in milling operation, and making modifications to the Roto-Jet™ tool prior to its use. Some of the takeaways during these workover operations are the following:

- Cleaning out a geothermal well with 10-¾” big hole completion that is totally plugged with scale using a CTU-conveyed Roto-Jet™ is doable by optimizing the tool configuration to enable it to provide more impact pressure to break/clean the scale. The use of the optimized Roto-Jet™ tool could be a good alternative to the conventional method of using a mill to remove wellbore scale.
- Some lessons learned were captured during the CTU-conveyed milling operation and these can be used during the preparations for future milling operations.

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