202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin

OTC-30386-MS

Pioneering Slickline Deployed Through Tubing Gravel Pack in Malaysia; Successful Case Study and Lessons Learnt

Ertiawati Mappanyompa, Ba Loi Trinh, Khairul Akmal Mazzlan, Izura Aripin, Etiqah Siti Noorashikeen M Sulong, and Nik Zarina Suryana Nik Khansani, Petronas; Robert Picou and Sharifudin Salahudin, Thru-Tubing Systems

Copyright 2020, Offshore Technology Conference

This paper was prepared for presentation at the Offshore Technology Conference Asia originally scheduled to be held in Kuala Lumpur, Malaysia, 17 - 19 August 2020. Due to COVID-19 the physical event was postponed until 2 – 6 November 2020 and was changed to a virtual event. The official proceedings were published online on 27 October 2020.

This paper was selected for presentation by an OTC program committee following review of information contained in an abstract submitted by the author(s). Contents of the paper have not been reviewed by the Offshore Technology Conference and are subject to correction by the author(s). The material does not necessarily reflect any position of the Offshore Technology Conference, its officers, or members. Electronic reproduction, distribution, or storage of any part of this paper without the written consent of the Offshore Technology Conference is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of OTC copyright.

Abstract

Formation sand production is a major concern in brown field operations, especially as the field depletes and water production commences. There are many methods to control sand production in primary well completion; however, it becomes more challenging in producers where no primary sand control is installed initially, and it starts producing sand later in the well life.

Selecting the right method for remediating these wells has become a hot topic with both Operators and Service Providers alike striving to discover effective and economical solutions for their brown-field operations. Currently, the solutions for through-tubing sand control in existing producers are screen hang-offs, through-tubing gravel packing[1] (TTGP) and chemical sand consolidation.

Through-tubing sand screen (TTSS) hang-offs above the producing zone, is an inexpensive sand control method. Unfortunately, these installations are typically short lived, often requiring regular well interventions due to screen plugging or erosion, or sand clean-out operations to remove sand accumulated in the production tubing. Alternatively, TTGP is a robust method to control sand production; however, more equipment is required to deploy the gravel pack which subsequently increases costs significantly in offshore applications. To simplify TTGP and make it economical, a major Interventions Service Provider devised a methodology to install TTGPs utilizing Slickine that reduces the overall installation cost tremendously. The methodology has been proven a great success in the US Gulf of Mexico where over 1,200 applications have been installed.

The pilot implementation of slickline deployed through-tubing gravel pack (SL-TTGP) was executed in three S-Field wells in late 2018 which were shut-in due to higher than permissible sand production. These were challenging intervals in that they were uphole recompletions between cement packers in dual string 9-5/8" casing which had produced sand.

The results from the installation proved that the methodology provides effective sand control and enables reinstatement of production from these wells. Further, the installations were achieved with lesser resources and at lower costs; less than half that of a CTU deployed TTGP. This success has led to further installations in the following year.

This paper presents in detail the case study of the pilot implementation of SL-TTGP, key successes, as well as critical lessons learnt during execution and production phase. It includes the challenges, risks and their recommended mitigation plans, as well as the well performance comparison before and after the implementation both in terms of production and sand count.

Introduction

S-Field is an oil field located about 50km offshore Sabah, East Malaysia that has been on production for more than 40 years. Majority of its wells are completed in sand-prone reservoirs with either gravel pack or stand-alone screens during their initial completion. In its late life, development of behind casing opportunities (BCO) has become a major production enhancement initiative by through tubing perforation of the undrained intervals. Sand-prone BCO intervals are usually either perforated and produced without downhole sand control or installed with a through-tubing sand screen (TTSS) hung off above the producing zone. TTSS is an inexpensive sand control option that typically has a short life span often requiring regular well interventions and change-outs due to plugging or erosion, and sand clean-out operations to remove sand accumulation from the production tubing.

With depletion and increased water-cut, some S-Field wells have started experiencing deteriorating or ineffective sand control and excessive sand production. This has resulted in choked-down production and even shut-in wells in some cases, triggering the search for an effective through-tubing remedial sand control solution. Commonly available through tubing sand control options include through tubing sand screen (TTSS), through tubing gravel pack (TTGP) deployed on coiled tubing and chemical sand consolidation. As a brown field, S-Field wells require a through-tubing sand control methodology that is both robust and cost effective to meet intervention economics.

One such methodology, a slickline deployed through tubing gravel pack (SL-TTGP) was proposed by a major through tubing (TT) Intervention Service Provider. It is a conventional TT sand control method that is deployed unconventionally that can reduce deployment costs by 50 percent as compared to conventional CTU-deployed TTGP. The methodology is widely used in the US Gulf of Mexico with great success. The premise behind SL-TTGP design is to eliminate or minimize the need for coiled tubing or other workstrings to deploy and complete the gravel pack. Slickline (SL) conveys the required downhole tools including screens, isolation packers and gravel pack proppant. In some cases, where large proppant volumes are required, most of the proppant can be delivered in a conventional gravel pack slurry and pumped down the production tubing from the surface. SL then finishes off the proppant placement. This is done to minimize the number of SL runs required to complete the gravel pack proppant.

Pilot deployment of this methodology was executed in September 2018 for three S-Field wells that were shut-in due to excessive sand production. Despite initial operational challenges, the SL-TTGP was successfully deployed in all the pilot wells, resulting in reduced sand production from >100 pptb to <5 pptb, and enabling the revival of production from these wells. These successes have paved the way to effectively unlock potential from other shut-in sand producing wells.

Candidate Selection

As in any intervention solution, selecting the right candidates for the application is vital for its success. The following key-criteria were considered in selecting the candidates for SL-TTGP.

Sand failure characteristic and sand count trend: While it is possible to manage sand production at surface, problems could be caused by erosional failure that occur downstream of the choke valves, as well as by sand build up inside the production tubing. These might lead to production downtime, or worse, loss of primary containment (LOPC). Historically, the S-Field candidates experience sand production of upto 200 pptb, making them candidates that are prone to becoming idle.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

Wellbore configuration and condition: Consideration on the wellbore configuration is also important in selecting the SL-TTGP candidates. As this is a (SL) conveyed operation, the well deviation needs to be <65 degrees. The required gravel pack (GP) sand/proppant volume to pack the perforation tunnels and annular spaces should be small enough for optimum slickline dump bailer placement (refer to Figure 1). Hence, it is recommended to limit the candidate to wells with perforation interval of <50 ft. As fluids will be pumped to place the GP proppant and pressure applied to the tubing string during the process, tubing integrity has to be assured in candidates selected.

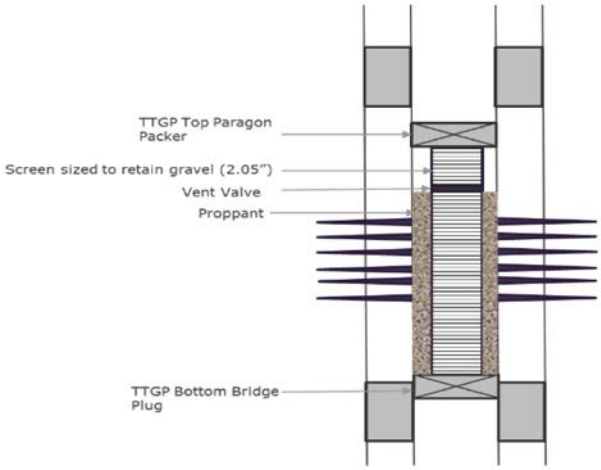

Figure 1—Gravel pack sand/proppant placement in perforation tunnels and annular space in TTGP installation inside production tubing

Production performance and economics: Candidate selected needs to have good reserves (> 0.2 mmstb) and productivity (PI > 1 bpd/psi) to be able to recover the cost of well intervention and ensure the well can sustain good production post SL-TTGP. The unit enhancement cost (UEC) for SL-TTGP is relatively low as compared to conventional CTU-TTGP. For S-Field pilot wells, the initial UEC was estimated within a range of USD2.0-2.50/bbl which made them highly desirable.

Pilot Candidates

The three S-Field pilot candidates are oil producers completed as dual completions inside 9-5/8" casing with well deviations between 15 to 45 deg. All three candidates are behind casing opportunities (BCO) that were perforated through tubing and were produced without downhole sand control. Sand production was managed passively through controlled drawdown until they were shut-in due to higher than permissible sand production rates. All three wells are gas-lifted and the developed BCOs were the only producing intervals at the time of the candidate selection.

In the 1st and 2nd well, the production interval is located above the original 9-5/8" dual production packer with cement packer annular isolation. In each well, the BCO was accessed through 20 ft and 30 ft of oriented perforations through the 3-1/2" 9.3#/ft short string which penetrates the cement packer, 9-5/8" casing and cement sheath in the casing-openhole annulus. Figures 2 and 3 illustrate the wellbore configurations for the two candidates.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudir

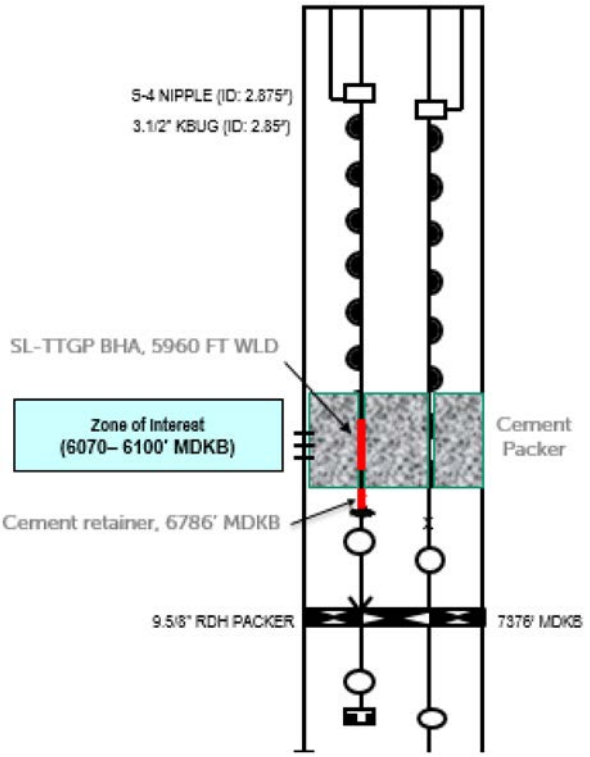

Figure 2—Wellbore configuration of Well A10S

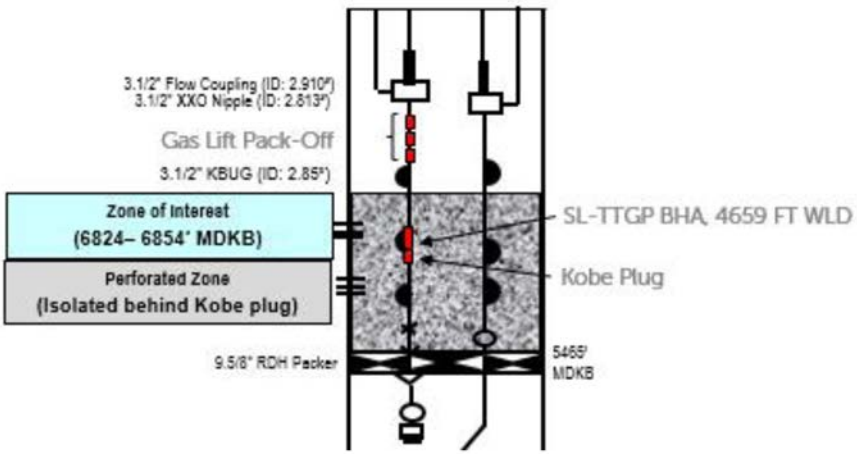

Figure 3—Wellbore configuration of Well A15S

The 3rd well was more challenging; the zone of interest was the top section of an existing gravel packed interval accessed via 20 ft of perforations in the 3-1/2" 9.3#/ft long string, as shown in Figure 4 above. The top of the existing initial gravel pack assembly was perforated during the BCO development.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

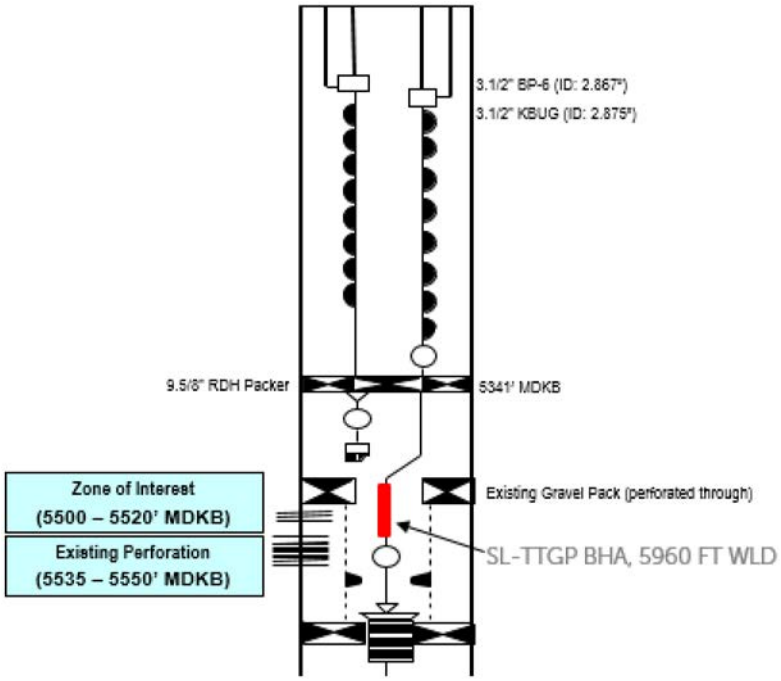

Figure 4—Wellbore configuration of Well A22L

SL-TTGP Design

The design of a SL-TTGP follows that of a conventional gravel pack with special attention being paid to the existing well completion where the SL-TTGP assembly is to be installed. As in conventional gravel packing, the goal is to effectively place graded proppant against the formation, perforation tunnels and annulus between the gravel pack screens and tubing. The graded proppant placed is then restrained by the gravel pack screen.

Downhole Tool Design

The installation design for a SL-TTGP involves critical evaluation of the existing completion configuration in the well; completion tubing size, ID restrictions, perforation location in relation to the completion tubing, perforation shot density, gun orientation and charge performance, tubing/casing and perforation annular space, well deviation, well and production status, etc.

The SL-TTGP tool assembly for this campaign is designed to fit inside the 3-1/2" production tubing and conveyed into place on standard slickline deployment tools. To enable deploying long assemblies, the SL-TTGP tool system is run in sections that fit standard slickline lubricator easing installation. Each assembly section has a polished bore receptacle (PBR) (2.20" OD) at the top that is used to convey the assembly and to locate it at the predetermined depth in the well. The next assembly section has a mating anchor latch and seal assembly (2.70" OD) that stings and seals into the PBR of the previous section, and so on. Each assembly run, starting from the second run, is over-pulled 500 lbs above its pick-up weight to ensure that the anchor latch seals have engaged into the PBR. Jarring down shears the running tool pins and releases it from the assembly for the next section to be run.

The SL-TTGP assembly is located on a base of either a tubing plug, bridge plug or sealbore sump packer, set ~5 ft below the bottom perforation. The bottom of the gravel pack screen assembly is either a bull plug or collet seal latch when a sealbore sump packer is used as the base. The gravel pack screen assembly is sized to fit in the 3-1/2" tubing, with 1.66" OD, 1.39" ID base pipe, 2.054" OD, and 10' in length. The screens straddle the perforation, with excess of 3-5 ft below and 5-10 ft above the perforation intervals. The blank pipe is sized the same as the screen base pipe and generally is 30-60 ft in length and run above the

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

screens. A 4-bladed centralizer of 2.7" OD, is run above each screen and blank section to provide positive centralization for the assembly.

Above the top screen section, a Sand Height Control Valve (SHCV is installed at the screen/blank pipe interface, it is an expendable/shearable check valve that is designed to prevent flow into the vent screen, down the blank pipe and out of the main screen during proppant placement. By temporarily plugging this flow path, bridging of proppant across the vent screen during proppant placement is eliminated. As with conventional gravel packing, it also allows for observation of a sand out or screen out pressure at the surface while pumping the proppant in place thus signaling that the screen and blank pipe annulus are properly packed. As a result, sand height in the blank pipe casing annulus can be calculated as done in conventional gravel packing operations. Once the desired sand out pressure is reached the valve assembly shears and falls to the bottom of the gravel pack screen assembly allowing full bore ID through the screen and blank assembly.

A short vent screen assembly (1.32 ft in length and 8 ga. screen opening) with removable vent plug and sealing profiles make up the top section of the SL-TTGP assembly. The vent screen with removable plug temporarily plugs off the top of the vent screen assembly preventing it from filling with proppant during proppant placement operations. This system allows for removal of the plug following proppant placement operations to allow for an open through bore of the gravel pack assembly. It also accommodates the installation of a gravel pack isolation packer which prevents proppant flow back during well production.

The whole deployment operation sequence of SL-TTGP is depicted pictorially below in Figure 5.

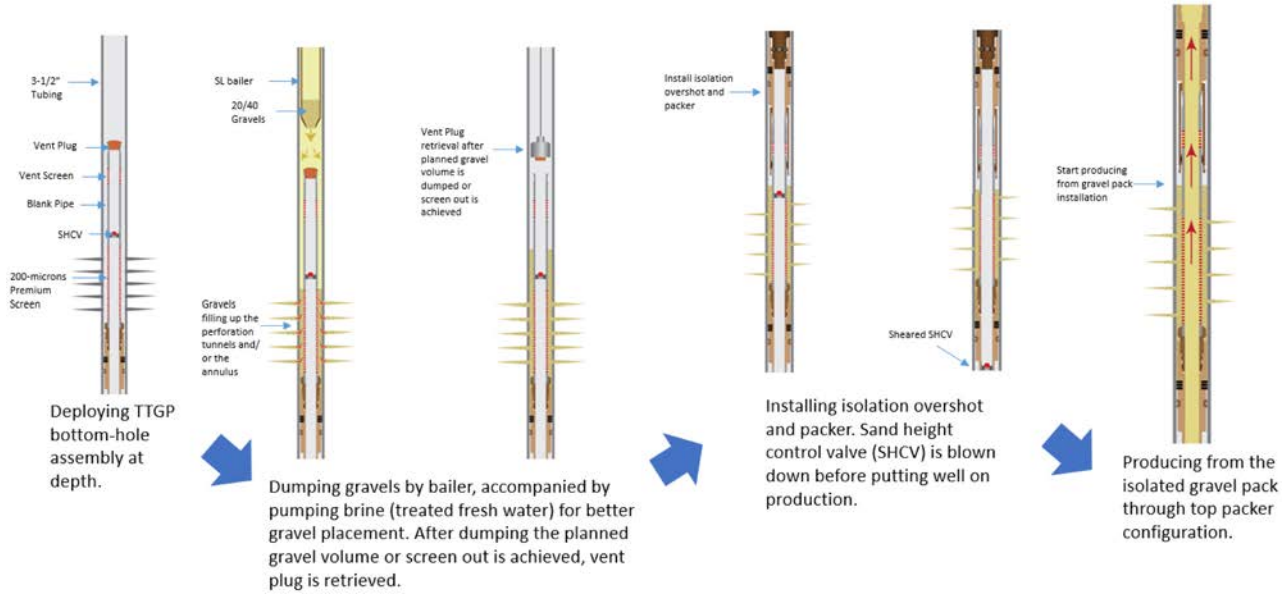

Figure 5—Summary of SL-TTGP deployment operation sequence

Gravel Pack Sand/Proppant and Screen Design

The sizing of the GP sand/proppant and the screen sieve opening for a remedial or TTGP is based on formation particle size distribution (PSD) as in a primary gravel pack design. Saucier's criteria of 5-6 times d50 from a PSD analysis is the design criteria for the GP sand/proppant size selection. The screen opening size is selected to retain the GP sand/proppant. The formation sand PSD curves, derived from offset well core samples, are shown in Figure 6. Based on the formation sand d50 (~100 microns), 20/40 GP sand/proppant size and 200-micron screen opening were selected.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin

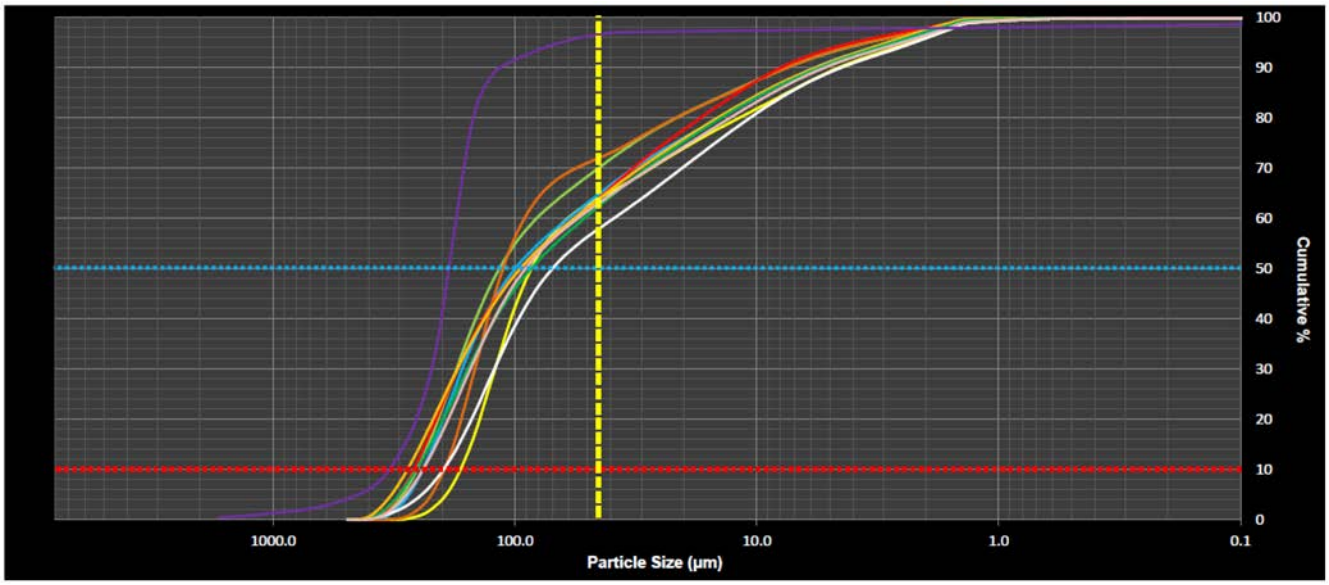

Figure 6—PSD Curves of formation sand samples

In TTGP applications, man-made ceramic proppant that has significantly higher (3x) permeability than that of normal GP sand is typically selected. Likewise, premium woven mesh screen is typically specified. In many cases these screens can be sized to retain the gravel pack proppant as well as a large part of the formation sand.

SL-TTGP Operations

The major steps in installing and completing the SL-TTGP are detailed below. Execution was performed according to the A15S, A10S and A22L sequence.

Preparatory Slickline Operation

Preparatory slickline work was performed prior to the start of the campaign to ensure that the well and tubing is ready for the SL-TTGP installation. This included reviewing well history and current status, recording wellhead pressures and performing slickline drift run to ensure tubing is clear to the intended setting depth.

Deployment of the SL-TTGP Assembly

The SL-TTGP assembly was deployed smoothly as designed, starting with setting a tubing plug about 5 ft below the perforation interval in A10S and A15S wells, and a sealbore sump packer in A22L. The SL-TTGP was deployed in 4 slickline runs in the 20 ft perforation interval wells and 5 runs in the 30 ft perf interval well, see Table-1 below.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudir

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudir

Table 1—Summary of pertinent details of SL-TTGP design and operation in the pilot wells

Well	TTGP Design	Proppant Volume (lbs)		No. of Bailer Runs (30ft x 2" Bailer)		Total SL runs	Operation Duration (hrs) – excluding rig-up	
		Plan	Actual	Plan	Actual		Plan	Actual
A15S	20/40 Gravel x 200µm Premium Screen	192	231	6	4	5 SL runs + 4 SL bailer runs + 3 runs to retrieve and set isolation packer	61	79
A10S	20/40 Gravel x 200µm Premium Screen	296	651	6	12	7 SL runs + 12 SL bailer runs	106	91
A22L	20/40 Gravel x 200µm Premium Screen	5,698	5,765	5	5	18 SL runs to clear tubing #20-Set base 3 runs to set SL-TTGP assembly 5 bailer runs to finish gp 8 sl runs to retrieve plug Run#9 to set pack-off	149	180

Deployment of Gravel Pack Proppant

Prior to commencing the GP operations, an injectivity test was performed; all 3 wells were observed to be sub-hydrostatic as there was high injectivity (in excess of 2 bpm) attained. Injectivity through losses into the formation aids in proppant placement into the perforation tunnels and tubing-screen annulus during gravel packing.

Gravel packing involves conveying and placing the selected proppant in the perforation tunnels and packing the tubing-screen annulus. With the SL-TTGP assembly already in place, measured volumes of GP proppant is conveyed in a 2" OD dump bailer (30 ft dump bailer section contains ~50 lbs of proppant). The opening of the bailer above the plugged vent screen is electrically triggered while pumping a small

volume of treated fresh water (TFW) at a desired rate of 0.3-3.0 bpm to assist depositing the proppant into the perforation tunnels and annulus.

For wells A10S and A15S, 4 and 12 dump bailer runs were required to complete the gravel packing, respectively. A22L was unique in that it had a large annular volume between the original gravel pack assembly and the tubing/GP screen, requiring 5,765 lbs of proppant to fill the void. This large proppant volume was conveyed in 3 batches; 2 batches in 35 bbls of gel slurry containing 2,700 lbs of proppant bullheaded via the short string and topped off with an additional 315 lbs conveyed in 5 bailer runs via the long string.

Retrieval of Vent Plug & Installation of Vent Screen Pack-Off and Isolation Packer

Post gravel packing, an assembly comprising of an overshot with indicator pins is run over the vent screen to ensure that the annulus around it is clear of proppant. Setting and jarring down on the vent screen plug shears the indicator pins, indicating that the plug is clear of debris and can be retrieved in the next run with a JDC overshot.

Vent screen plugs in A10S and A15S wells were retrieved in two SL runs, followed by one SL run to install the vent screen pack-off and annular isolation packer. A22L well required nine SL runs to remove excess proppant located above the top of the vent screen assembly. Excess proppant was dumped due to failure of the SHCV to shear during the GP operation. A longer section of blank pipe between the main screen and vent screen could enable higher pressure to shear the SHCV and prevent this occurrence in future wells.

Shearing of SHCV

The final step in the SL-TTGP deployment operation is the shearing of the SHCV in order to establish communication between the perforations, gravel packed interval and production tubing to enable production.

Because no clear screen-out was achieved in any of the pilot wells SL-TTGP implementation, the shearing of SHVC was performed manually. It was done for A10S and A22L, with gradual pressuring of the tubing at 0.5 – 1.0 bpm, until the SHCV sheared at 1950 psi and 1400 psi, respectively.

With the exposure of tubing holes once gas lift pack-off assemblies were removed to allow well entry, it was decided not to include SHCV in the A15S SL-TTGP operation. This was to mitigate the potential risk of not being able to pressure up the tubing to shear the SHCV. The design of the SHCV does allow flow of the well if not sheared however it would leave a restricted ID due to the check valve assembly.

SL-TTGP Operations Challenges

There were several challenges faced during the execution which caused the actual operation to be longer than planned in two of the wells.

Losses into the formation: The common issue in all three wells was high losses into the target reservoirs as they are below hydrostatic pressure, with injectivity of >2 bpm. Though high injectivity through losses aids proppant placement into the perforation tunnels and tubing-screen annulus, better anticipation of this occurrence is required in planning the activity.

Uncertainty in proppant volume estimation: The estimated GP proppant volume was found insufficient during execution, necessitating the unplanned mobilization of additional proppant to site when screen-out was not achieved even after 100% excessive proppant had been dumped in all three wells. All the candidate wells had been flowing with formation sand production, possibly leaving voids in the formation behind casing. This introduced a major uncertainty in the proppant volume estimation. Voids behind casing, induced by prior formation sand production, needs to be better accounted for and excess proppant volume mobilized to site to avoid operational delays.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

Sand Height Control Valve: The SHCV shear setting did not adequately match the length of blank used thus allowing covering of the vent screen top with proppant prior to shearing in one of the wells. Lowering the shear pressure or lengthening the blank pipe could have remediated this occurrence. Still the well was successfully completed requiring only additional 9 slick line runs to bail proppant off the top of the vent screen top assembly

Pre-job well preparation: Pre-job well preparation includes determining the actual existing hold-up depth in the well prior to setting the base bridge-plug/packer for the SL-TTGP assembly. This was not well managed in A22L well, requiring 18 bailer runs over 4 operational days to clear formation sand down to the required depth to set the sump packer.

Results & Conclusions

The pilot SL-TTGP in S-Field is deemed an operational and economic success enabling the reinstatement of production from the shut-in pilot wells. Several lessons learnt have been captured to aid in planning and execution for future applications. Production results from the pilot implementation is reviewed in detail in the section below. Table-2 summarizes the Pre- and Post SL-TTGP production results in the three pilot wells.

Table 2—Pre- and Post SL-TTGP Production Results

Parameter	Well A10S		Well A15S		Well A22L	
	Before	After	Before	After	Before	After
Well Status	Shut-in	Flowing	Shut-in	Flowing	Shut-in	Flowing
Choke Size (1/64")	64	64	60	64	48	48
Liquid Production Rate (BPD)	1500	650	1300	550	1000	380
Water Cut (%)	88	92	87	89	79	82
Oil Production Rate (BOPD)	180	50	170	60	210	70
Sand Count (pptb)	50	3	60	2	100	0
Sand Production Rate (lbs/d)	75	2	78	1	100	0
Productivity Index (stb/psi)	3.7	1.0	1.6	0.6	1.3	0.3
PI/foot (stb/psi/ft)	0.12	0.03	0.08	0.03	0.04	0.01
Actual UEC (USD/bbl)	<10.00		<10.00		<10.00	

To date, the pilot wells have seen over one year of post SL-TTGP production. The main observations after 1 year of production in the S-Field wells are:

- The SL-TTGP application was highly effective in reducing sand production in all the 3 pilot wells from >100 pptb to <5 pptb. Sand production history of the candidate wells is shown in Figure 7 below.
- Total liquid and oil production rates post SL-TTGP installations were lower than pre-shut-in production. This indicates induced skin both irreducible and removable. Irreducible skin results from insufficient perforating. The wells were perforated with 4 SPF which is below what is required for the flow potential of the wells once gravel packed. Perforating shot density of +-12 SPF with largest entry hole diameters available should be used in future wells. Induced skin results from excessive fluid losses of unfiltered fluids and unbroken polymers. Future wells should include

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

improved well completion practices used in conventional gravel packing designed to prevent formation damage during the completion.

- Post-production stimulation using an acid system was performed in 2 of the 3 pilot candidates which resulted in improved production, suggesting that the induced skin was caused by removable formation damage.
- Actual UEC values realized were much higher than initially estimated due to the lower post-production rates. Despite the higher values, UEC values demonstrate profitable oil development.

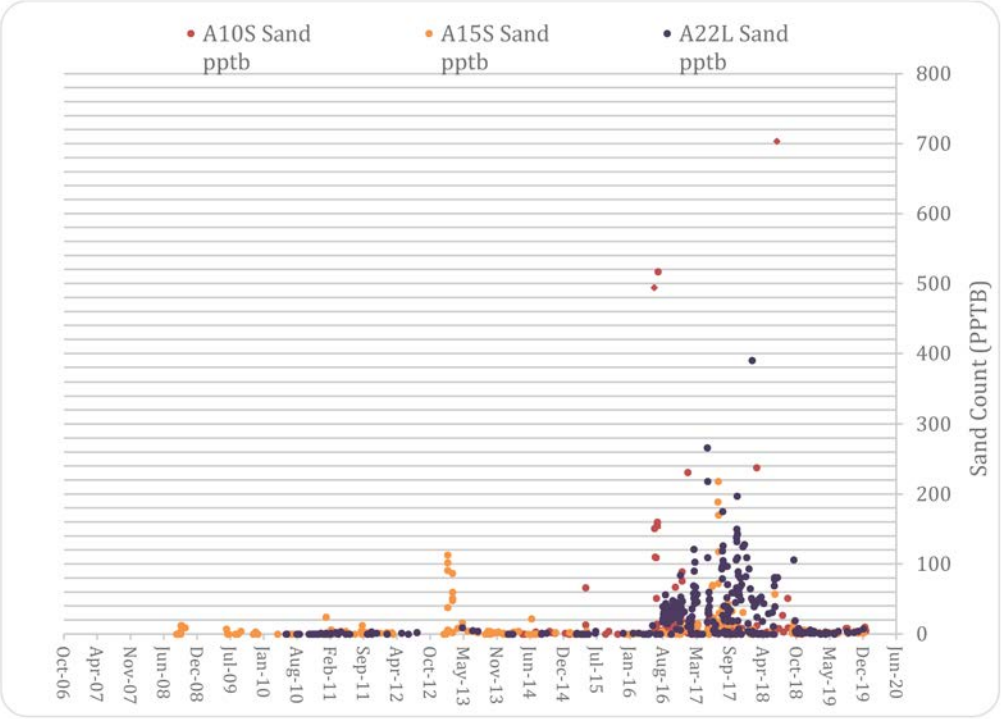

Figure 7—Pilot wells solids production history

Productivity Impairment Evaluation

Productivity Index (PI) comparison analysis with and without SL-TTGP was performed for the three S-Field pilot wells. It was found that the well productivity was 2-3 times lower than expected for TTGP application (refer to Figure 8). Well performance analysis on flow ID reduction from the SL-TTGP installation indicate that there is insignificant impact on production. In all 3 wells, productivity was reduced by about 60% post SL-TTGP, and it was showing a reducing PI trend after that. The suspected damage mechanism is particulate damage during the TTGP process and later through fines migration during production.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

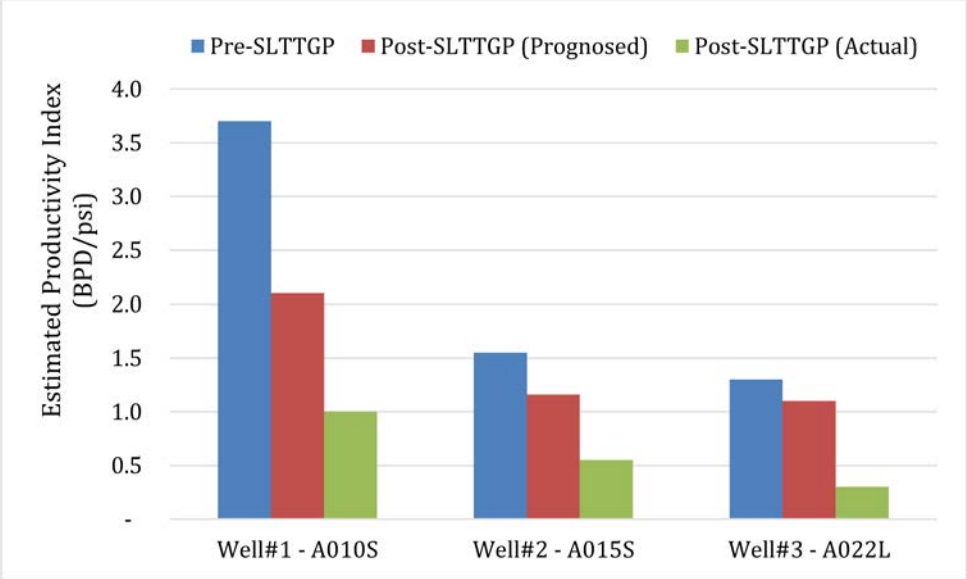

Figure 8—Productivity Index comparison chart

As such, in November 2019, A10S and A22L were treated with an acid system to remove near wellbore damage. The treatment was pumped via CTU to 5 ft above the TTGP assembly and left to soak for 4-6 hours before being over-displaced into the formation with a post-flush.

In A10S post treatment productivity increased close to the pre-SL-TTGP productivity during the 1st month after the chemical treatment. However, it reduced back to its post SL-TTGP productivity in the following month. In A22L, after the chemical treatment, productivity increased but is still under evaluation.

The results from the stimulation confirmed through multiple well tests, improved productivity. These results point to formation damage through the TTGP process and potential fines plugging during production.

The following are potential damage sources that may have influenced the production results:

- Through tubing perforation: The target reservoirs in all three pilot wells involved BCOs that were accessed by through-tubing perforations in the 3-1/2" tubing. As in any through-tubing perforation, the perforation is designed for maximum penetration to mitigate the risk of insufficient reach into the formation due to small gun selection, however it lacks shot density (4 spf) and flow area for gravel packing. This could lead to poor perforation packing and higher pressure drops, see figure 9 below. To mitigate this, it is recommended to reperforate the interval with perforating systems that deliver bigger entry hole diameter and higher shot density.
- Debris from production tubing: Production tubing has debris coating its walls which may be dislodged and carried into the perforations during the GP process which is potential source of damage. To mitigate this, it is recommended to run brushes and a bailer to clean the tubing walls and recover the debris.
- Fluid damage: There was no measurement and monitoring of the treated fresh water (TFW) quality prior to its pumping into the production tubing to assist proppant placement, and it was bullheaded directly from the storage tank, without filtration. Enough foreign material in the water could cause near wellbore damage to the well.
- In A22L, as the required GP proppant volume was large, a slurry of gel and proppant was mixed and pumped downhole through the short string in the well in order to fill up the large annular volume behind the long string prior to the designed slickline bailer dumping of the GP proppant in the long string. Gel quality was questionable, presenting possible cause of formation damage.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

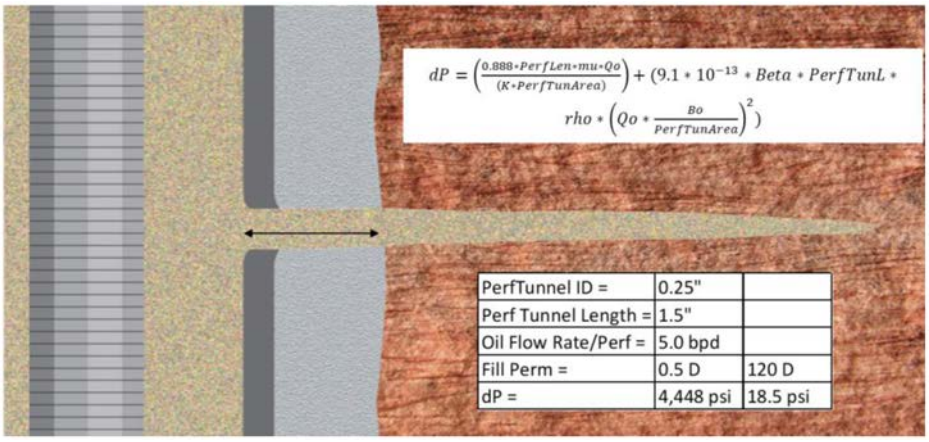

Figure 9—Perforation pressure drop estimation with formation sand vs. gravel pack sand

Lessons Learnt and Recommendation

The pilot implementation of SL-TTGP in the S-Field provided several lessons learnt that were applied in subsequent campaigns to improve execution effectiveness, project time and costs, as well as well productivity. These are discussed below:

- To be more certain of well integrity and wellbore conditions of the candidates. It is important to be well prepared to avoid unplanned and unaccounted for activities during execution, as what happened for A15S (well integrity) and A22L (unaccounted for hold-up depth).
- To better estimate the required proppant volumes to minimize unplanned mobilization, especially for candidates that have been producing sand prior to the SL-TTGP installation.
- To limit candidates to those with high initial PI >1 bpd/psi. A reduction in PI is expected in any TTGP application. Thus, it is important to select wells with sufficiently high expected initial PI for TTGP application such that production post-TTGP will still be economical. Pre job modeling with nodal analysis can identify choke points in the completion design such as inadequate perforating and establish realistic completion goals.
- To assume higher post-TTGP skin during economic evaluation to ensure robust economics for the activity.
- SL-TTGP is best applied to newly perforated zones as it provides clean perforation tunnels for GP applications. In applications for existing perforations with history of sand production, it is recommended to re-perforate the interval with large entry-hole diameter and high shot density, and to perform squeeze packing (at ~0.5 ppa) of the potential void behind casing created due to sand production, prior to the SL-TTGP execution. Packing the void is essential to avoid causing failure to the gravel pack installation. For zones with high fines content, applying fine stabilizer to the sandface/formation is recommended before commencing the squeeze packing.
- For any reservoir where sand failure is predicted to happen sometime during its production life, its development (either during initial completion or through tubing) should include downhole sand control as proactive measure, instead of reactive. I.e., sand control should be applied from the very beginning, instead of applying it later after failure takes place. In Malaysian reservoir environment where sand prone zones normally have high fines contents, the recommended strategy for BCO development is to apply resin consolidation and fine stabilizer, plus gravel packing, if economics warrant it.
- To employ clean and formation compatible carrier fluid to minimize risk of formation damage by filtering it to NTU < 30 and total suspended solid of < 0.3 before bull heading it into the well.

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir

- To apply pre- or post- job stimulation whenever applicable. To minimize the risk of chemical damage to the gravel pack screen, stimulation job should be non-acidic. In the case of S-Field, stimulation was performed on 2 of the 3 SL-TTGP wells. However, more time and well test is needed to conclude the effectiveness of the post-job treatment.

Acknowledgement

The authors wish to thank the management of PETRONAS and Thru-Tubing Systems for permission to publish this paper. Special thanks are also extended to the Thru-Tubing Systems service personnel for their technical and onsite installation support for the SL-TTGP system. The authors also wish to thank Deleum and SVP field personnel who worked on this project and contributed much to making the operations safe and successful.

SI Metric Conversion Factors

gal × 3.785 412	E − 03 = m3
ft × 3.048*	E − 01 = m
in × 2.54*	E + 00 = cm
psi × 6.894 757	E + 00 = kPa
bbl × 1.589 873	E − 01 = m3
mile × 1.609 344*	E = 00 = km
lbm × 4.535 924	E − 01 = kg

* Conversion factor is exact

References

1. SPE 99691 "First Through-Tubing Gravel-Pack Recompletion Performed in Japan" Authors: Masaaki Numasawa, Japan Petroleum Exploration Co. Ltd, Sharifudin Salahudin, Hiroyuki Hashimoto, Chen Yee Choy, Halliburton Energy Services and Shinichi Mitsuda, Mitsubishi Gas Chemical Company Inc. Presented at the SPE/ICoTA Houston 4-6th April 2006

202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudin@suteraenergy.com; 202.187.192.127; sharifudin.salahudir