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Multi Zone Single Trip Gravel Pack System Deployed On Hydraulic Workover Unit: Holistic Approach To Optimize Drilling And Completion Cost In The Mahakam Delta

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Abstract.

The Multi Zone Single Trip Gravel Pack (MZSTGP) system has been proven as the main solution for developing shallow reservoirs and overcoming sand production issues in marginal sand prone wells in the Mahakam Delta, Indonesia. Robust operating procedures and completion equipments have been developed to assure safe and efficient operations through conventional swamp or jack up rig operations since 2006.

Due to marginal reserves being currently available and the high cost of conventional rig utilization to perform MZSTGP completion, Pertamina Hulu Mahakam initiated completion of the well using a rigless technique to install gravel pack completion with Hydraulic Workover Unit (HWU).

This alternative solution is the main driving factor as a new way to complete the MZSTGP rigless operation and enables the delivery of typical marginal wells economically at the Mahakam Delta swamp area. This has resulted in potential significant well cost saving up to 37% compared to conventional rig cost, or approximately equivalent to half a million USD along the completion phase.

Post rigless gravel pack operation, production stabilized at expected rate and the well has no restrictions to keep producing at this rate or even higher. This new frontier solution of MZSTP rigless operation can be considered as the first successful rigless 7" MZSTGP installation at swamp areas worldwide with no NPT and safety issue.

Keyword: *rigless completion, multizones gravel pack, hydraulic workover unit, sand control*

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1 Introduction

The Mahakam oil and gas block is located in the East Kalimantan Province of Borneo, Indonesia and the field started to produces in the 1970s. This block consists of 4 gas fields which are Tunu, Sisi-Nubi, Tambora, Peciko and two oil fields which are Bekapai and Handil.

The reservoir layer is mainly fluvial-tidal deltaic deposit with inter-bedded layers of coal and shale. Initially, oil and gas was produced only from the main reservoir, but in the effort to boost production output, the Shallow Zone reservoirs were contributed in the late 1990s. This reservoir mainly consists of consolidated sands forming small pockets and thin heterogeneities layers.

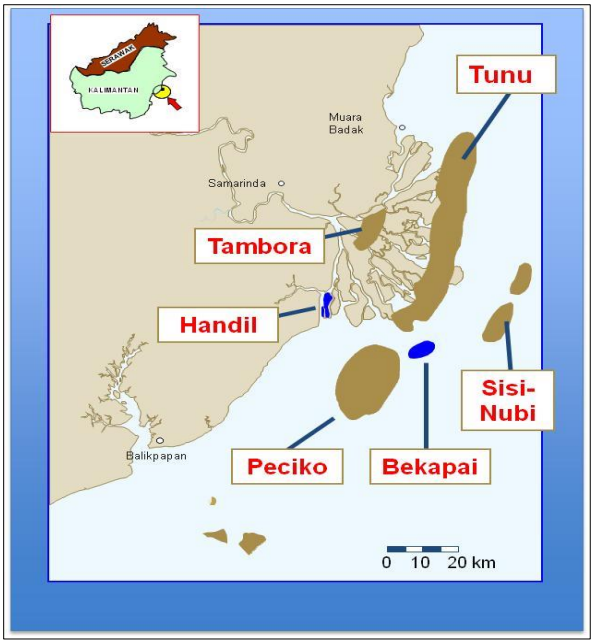

Fig.1 Tunu Field Location

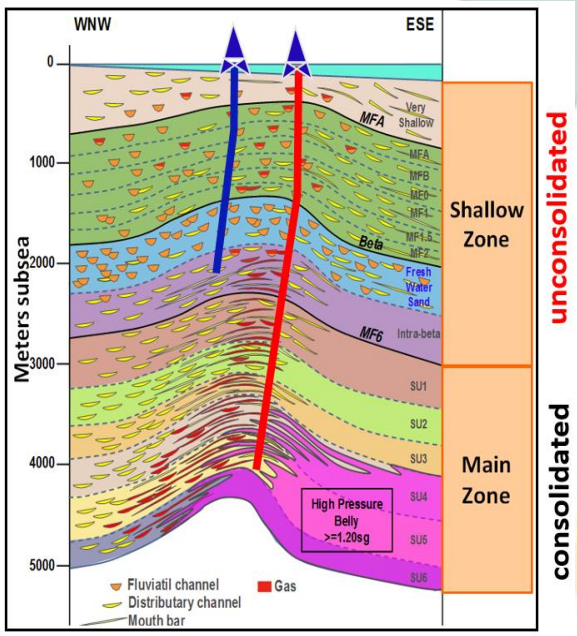

Fig.2 Reservoir Depth in Tunu Field.

Weak consolidated sands properties are found at depths between 1,800 and 4000 mTVD. The gross interval required sand control approximately over 1,000 m up to 3,000 m long. Most wells will have five to ten sand prone zones distributed throughout this interval length. As shallow reservoirs consist of many small reservoir pockets, MZSTGP is deemed as an economic solution for multi-layered small reserves in sand prone reservoirs and selectivity between zones is required to optimize oil and gas recovery.

The Tunu Field is a gas field in the Mahakam Block which has been produced since the 1990s. Initially, the Tunu Field was developed and produced from the main zones reservoir. In order to maintain

cumulative gas production, shallow zone reservoirs were started to be drilled and produced in 2008. This shallow

reservoir interval depth can be found up to 1,800 mTVD, that was mainly characterized as non-solid sand or commonly called unconsolidated sand.

A review of the sand control technique in the main zones reservoir showed that the in-situ sand unconsolidated method with MZSTGP was considered as the effective solution to overcome sand problem and increased cumulative Tunu Field gas production. Furthermore, proper sand control placement into the wellbore could mitigate risk of damage to the production facility, potential sand disposal issue, damage to well accessories, and lead to uneconomical production.

Multi Zone Single Trip Gravel Pack (MZSTGP) has been developed and applied to cut rig time since early 2006. It enables saving of 3-6 days of rig time depending on the well configuration. This method provides operation time savings of up to 7 days (depending on the number of perforation zones) compared to the classic conventional Stack Pack Gravel Pack method which is deemed as an uneconomic completion method.

Two types of MZSTGP are currently deployed in Mahakam depending on well requirement. Single String (SS) is used mainly for long intervals with high risk of fluid losses while the more economical Dual String (DS) is deployed in shorter intervals with less risk of cross flow and fluid losses. To ensure the deliverability of sand control technique and cost effectiveness, the field candidate required 7" Single String MZSTGP.

Specific tools and equipment such as screens with opening and closing sleeves were designed and deployed to ensure the whole process installed safely. One of the important features is utilization of a dropping table
system to handle multiple unshearable pipes. This was developed for two different systems through engineering design. It allows securing the well in less than 30 seconds.

To date, more than 200 wells have been safely completed without any major well control issue with conventional rigs. The robust safety approach did not hinder operational performance as proven by very low Non-Productive Time (NPT) since 2008 in the Tunu Field which contributes 45% of the total gas production from the Mahakam gas block.

Evaluations were considered to identify cost savings by utilization of Hydraulic Workover Unit (HWU) to do the MZSTGP completion compared to conventional rig in term of daily cost. On average, MZSTGP system installation consumed 40% of total operating rig time as the main driving factor to find an alternative solution for cumulative operation cost saving. Overall predicted savings were approximately US$ 8.1 million per year per swamp and with the possibility to extend the workscope and saving even more in well abandonment prior to sidetrack drilling well.

Hydraulic Workover Unit (HWU)

"Hydraulic Workover Unit (HWU)" are words rarely heard in Pertamina Hulu Mahakam drilling operation, unless used for intervention projects. However, HWU do serve a good purpose when used correctly for a specific objective such as completion, well abandonment or other well workovers. In the event where rig cost is considered premium, HWU can be consider as a viable alternative solution.

The Hydraulic Workover Unit (HWU) is a versatile, cost saving and safe tool to perform workover, well abandonment, and any well intervention. HWU units are designed according to the highest standards and incorporate with operation requirements. This unit is a portable and compact unit that has a system to push-in and pull-out tubular into the wellbore and is compatible for land, swamp and also offshore operation as below.

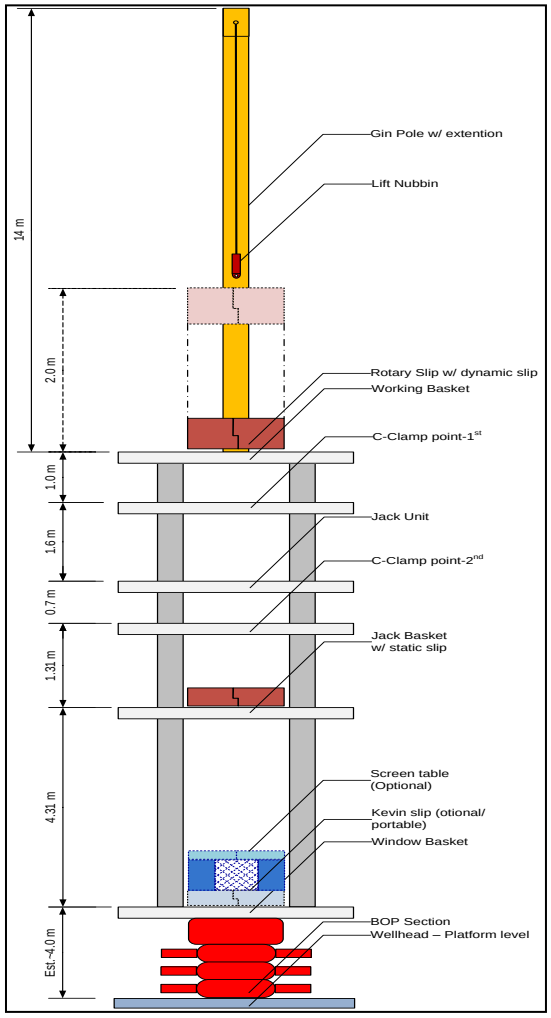

Figure 3 - HWU 340K Specification.

Commonly, HWU is one of the well intervention solutions which can be used to install or remove tubular in-out of the well. The pipes are push-in and pull-out of the well using hydraulic cylinders. Each stroke on hydraulic cylinder provides vertical movement of approximately 3 m, shorter than conventional rigs. The use of hydraulic cylinders allows perfect control over tubular movements and eliminates the use of a large mast construction which is present on conventional drilling rigs. HWU have lift-force capacities ranging from 150,000 lbs to 600,000 lbs, and are capable of performing a wide range of workover services, away far from conventional rig pulling capacity that is able to provide a tensile capacity of up to 1,500,000 lbs.

Moreover, gin pole lifting capability on HWU is up to 14 m above working basket level. This unit is designed to be able to lower tubular pipes without using the top drive. The tubular movement is driven by HWU gin pole, where the tubular connection is made up with a power tong that can be installed at both ways on work basket and window basket.

Figure 4 - Tubular Connection Process using Power Tong.

Typically, the well platform footprint area in the Tunu Field is designed as slim as possible and required a compact structure due to wells location which are widely scattered over the field with limited area. Because the well candidate is located in the Tunu Field, compact HWU is a fit solution to be utilized. MZSTGP's work activities are supported by multiple vessels (Accommodation Barge, Pumping Barge, Waste Barge, Completion Barge, and Logistic Barge) to deliver the well completion phase.

7" MZSTGP Working Method

Multi Zone Single Trip Gravel Pack (MZSTGP) is designed to minimize multiple pipe tripping associated with compartmentalized gas reservoirs. This system has been developed and installed in completions throughout the world since the 1980's. The MZSTGP system selected for the Mahakam delta developments is unique because it required the following features:

- Positive individual zone isolation.
- Circulating position with real time annulus pressure monitored.
- Service tool testable prior to treat each zone.
- Isolation systems testable prior to inject fluid to each zone.
- Positive tool positioning with set down circulating and set down squeeze.
- Reduced length polished OD service tool without wash pipe extending below services tool to reduces the potential sticking out length.
- Screen Communication System enhances GP and production flow path.
- Selective profiles for production sleeves can be accessed mechanically via slickline, wireline or coil tubing.

Compared to a stacked sand control completion, a Single String MZSTGP system can save up to 52% rig time by reducing the extra trips on completion running step from setting sump packer on the lowest zone to POOH and laying down the service tool after the top zone sand control job.

There are several strict criteria and limits that must be met if a well will implement using 7" MZTGP system, such as:

- Open hole size : 8.5"
- Rat hole length : 40 mMD
- Minimum distance between perforation zones : 27 meter for HRWP and 50 meter for FP
- Maximum distance between the top and bottom perforation zones 400 meter, otherwise the MST operation will be run in two trips
- Maximum Inclination across GP section : 50° (outside GP) and 55° (inside GP)
- Maximum DLS : 4°/30m at all section
- The minimum length ratio between blank vs blank pipe: 1: 1
- Sump packer is installed in a range of 2-4 m below bottom most perforation.

Tubing Conveyed Perforation (TCP) is selected as the perforation technique to be applied. TCP gun equipped with explosives material inserted to the gun carrier and run into the wellbore conveyed by tubular string to perforate target zones. The type of explosives (gun and charge) used are as follows:

- Gun size: 4-5/8"
- Maximum length of gun: 5 m
- Shaped Charge type: Big Hole
- Number of holes per foot: 12 spf
- Charge weight: 39 gr

The 7" MZSTGP basic components of a stacked single zone sand control system include the following: The outer assembly, which is installed downhole as a part of the production components is made up of the Gravel Pack Packer, Opening and Closing Sleeve, Safety Shear Sub, Blank Pipe, Production Screen, Indicating Seal Assembly, and Sump Packer. The service tool assembly is composed of Hydraulic Setting Tool, Crossover Tool, Circulating/Indicating Valve, Wash Pipe, and production/monitoring sleeve Shifting Tool.

Main Features of the MZSTGP System

Autolocator assembly provides a repeating cycle to allow the service tool to go from set down to run through. In the set down position, the service tool profile is latched into a supported collet to take set down loads of up to 100,000 lbs. The run through position allows the profile to pass through the collet with no indication.

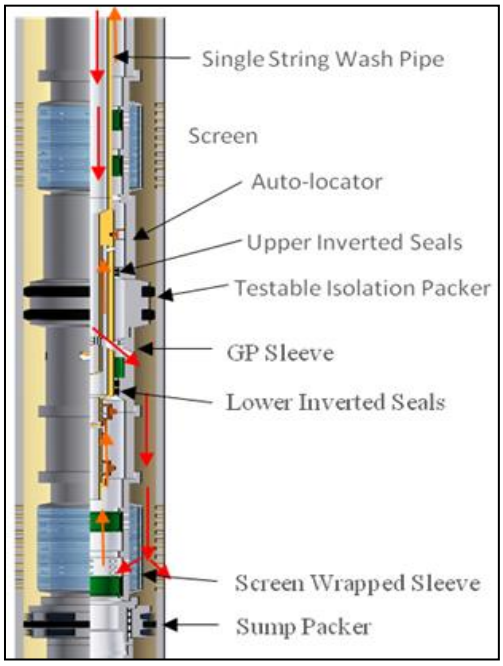

Figure 5 - Cross section of the MZSTGP System.

MZST isolation packer is used to provide zonal isolation between treatment intervals. It is a tubing mounted dual element packer with a self-contained setting tool. The setting tool contains a rupture disk which is actuated and gives a positive indication of packer setting. During treatments, hydraulic holds down buttons are actuated with internal frac pressure and provide the force necessary to hold the packer in position during high pressure treatments.

MZST Closing Sleeve is opened with the open only shifting tool to perform sand control treatments then closed with the close only tool to provide isolation for the zone. The closing sleeve contains additional bonded seals incorporated for sealing redundancy.

Circulating Valve Indicator sub contains a profile, which is used to shift the washpipe circulating /isolation valve on the lower end of the crossover service tool from open to close and back again.

Hydraulically actuated mechanical shear sub contains a hydraulic release mechanism which is able to carry the full load of the assembly into the wellbore. This prevents the load from being carried by the shear joint shear screws allowing long heavy assemblies to be run without fear of premature shearing.

Screen wrapped selective production/lower monitor sleeves are assembled as part of the base pipe for the screen assemblies and provide zonal isolation as well as open access to monitor the zones during treatment. Selective profiles with up to 5 positions provide shifting selectivity during production phase of operations.

De Crippler Sub with sleeve test profile provides engagement of the end of the service tool to allow "de-crippling" of the open only shifting tool. Once de-crippled an upper housing also contains a shearable sleeve profile which may be engaged by the open only shifting tool to ensure proper operation.

Test Sub contains a glass disc to allow a low pressure test of the assembly during makeup on rig floor.

Lower Seal assembly consists of Indexing mule shoe with indicating collet and locater seal assy. The Seal assembly locates on the sump packer with set down weight and also allows an upward snap indication for verifying seal position.

Sump Packer is a drillable permanent type packer used to establish bottom zone isolation and reference depth.

Gravel Pack Stimulation

High Rate Water Pack technique (HRWP) is a derivation of the conventional gravel pack method. HRWP procedures are considered as options for the Tunu Shallow reservoir as they are known to give results with lower skin values and better productivity compared to wells with conventional circulating gravel packs. With the very close gas water contacts characteristic of the Tunu Shallow zone, the frac-pack technique becomes too risky, as water breakthrough impacts to production. For these reasons, HRWP is considered as the best slurry placement method in the Tunu Shallow wells.

The high rate formation packing technique utilizes low viscosity carrier fluid and low concentration proppant pumped at rates above formation fracturing pressure. The HRWP is designed to be pumped above fracturing pressure, but fluid inefficiency results in a short fracture of 5 to 15 ft being created, thus bypassing the near wellbore damage caused by drilling, cementing, and perforating.

The size of the proppant selection refer to the Saucier (1974) method with the median of proppant size (D50) is not greater than 6x the median size of the formation sand (d50). Based on formation sand analysis data in the Tunu shallow area previously discussed and shown below, the proppant size obtained in accordance with these conditions is 20/40, or equivalent to a minimum of 410 microns. The 12 gauge screen is suitable for use with both 20/40 and 16/30 mesh proppant. Therefore, the switch to larger mesh proppant was easy to make as no change to completion hardware was required.

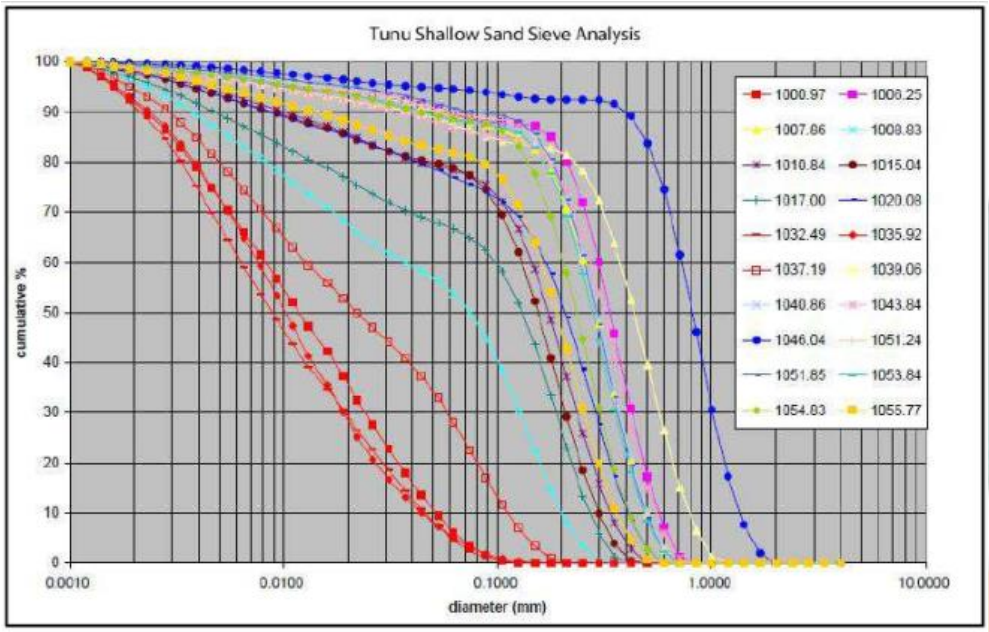

Figure 6 - Tunu Shallow Formation Sand Characteristics Curve.

Gravel Pack carrier fluid is used to deliver proppants into the formation using a fluid technology known as Viscoelastic Surfactant (VES). VES is a non-damaging fluid that uses a special surfactant as a gelling agent to boost the viscosity of the liquid. With well-controlled viscosity ranging from 15-20 cP, proppant can be delivered and fulfill of the screen or more precisely on the annulus between the screen and the perforation hole without any potential proppant bridging during the pumping process.

The objective of a HRWP treatment in an unconsolidated formation is to achieve more fracture width and less fracture half length. The purpose is to create a short fracture to bypass the near wellbore damage caused

by drilling fluid invasion, cementing, and perforating. As in conventional fracturing treatment, HRWP fracture width is determined by its relation to net pressure response. The higher the net pressure gained during the treatment, the more fracture width has been created in the reservoir rock. A high fracture conductivity value is also an indication that good packing has been achieved in the perforations. Net pressure gained is observed in real time through live annulus monitoring during the treatment. Screenout pressure at the end of treatment has to be considered to indicate proper proppant placement. If necessary, re-stress procedure is to be applied to ensure annular proppant packing.

2 Methodology

Well Data

TN-AAXYZ as the well candidate is located at Mahakam Delta. There are two zones gravel pack candidate which have average permeability 1150 mD equivalent to average permeability value of Tunu field. Reservoir pressure range from 1400 to 1600 psi respectively to both zones. All zones are planned to be treated with HRWP treatment having total depth of 8.5" hole at 1780mMD with maximum inclination at 40 deg in front of target zones and 109 m total length from top to next reservoir layer. Based on the above technical completion requirement, TN-AA371 is considered as an ideal well candidate and all operation challenges are suitable to MZSTGP requirement.

The Challenges of MZSTGP Installation using HWU

Barge Arrangement.
Rigless MZSTGP operation definitely requires a large barge deck space to transfer logistic and accommodate completion equipment required and deliver to the platform on time. Furthermore, small HWU platform deckspace at TN-AAXYZ, MZSTGP installation requires multiple barges to accommodate all equipment to be installed into the well. The five barges used during TN-AAXYZ completion are:

- Accommodation barge as main working barge
- Stimulation barge as a pumping barge
- Waste barge
- Logistic and Chemical barge
- Completion barge to store all completion items, such as tubing, screen, packers, and BHA

In line with the preparation, barges inspection, audits, and readiness are highly important aspect to cost and safely complete the HWU MZSTGP operation. The proper planning and an adequate risk assessment are the key to ensure reliable and proper completion process. Throughout this audit, the completion supervisors are able to calculate accurately in term of designing and equipment spotting, due to the lack of free space on the deck area in each barge. Specialized fit to purpose setup also could offer substantially improved efficiency and safety throughout the rigless completion. However, strong teamwork expertise and technical background from all parties involved are needed to deliver the new frontier of rigless operation.

Figure 7 - Placement Location and Barge Position.

Health, Safety and Environment Factors. Safety commitment and job risk analysis from all relevant parties are the key safety envelope respectively to the entire range of completion activities associated to the rigless gravel pack project. MZSTGP rigless operation is classified as a complex operation involving multiple heavy lifting activities that are considered as main potential risk for the whole operation exposed to all personnel involved.

On the other hand, the risk of working at heights on limited space working basket is contributed and increased risk severity level while working at limited areas along with high pressure pipes during pumping proppant, particularly to those personnel exposed in the stimulation barge area nearby to the high pressure fracturing pump.

To mitigate those potential risks and challenges, the completion supervisor plays an important role to describe all the risks, prevention, and mitigation that might occur during the operation. All personnel involved have to inform job planning and routine activities related to occupational safety factors by means of the Pre Job Safety Meeting (PJSM) which takes place on each shift of the working schedule either in day or night shift. Overall, the entire operation was performed in a safe manner and no HSE incidents were recorded throughout the entire rigless completion.

Figure 8 - Pre-Job Safety Meeting (PJSM).

HWU Limitation. HWU has no top drive system and limited pulling capability (traveling). This unit has low traveling speed and limited vertical movement with approximately 3 meters stroke length for the tubular
traveling capability. Thus, more strokes are required to run a joint of tubing, which impact to slower running speed in comparison to a top drive-equipped conventional rig. The maximum 3 meters lifting capability are far from ideal in tubular handling requirement for lower completion assembly. Particularly, handling lower completion with HWU required special precaution and risk assessment as it is not recommended to place slips in the area of the tool make up and run variant MZSTGP assembly such as screens, packers and other equipment.

Crane Limitation. Equipment movement from the barges to the platform was assisted by the crane (Figure 9). In addition, most of the gravel pack assembly (e.g., screen, isolation packer, blank pipe, etc.) were run in hole (RIH) using a crane. The length of the equipment can be a concern as the equipment must be lifted above the work basket. For the TN-AAXYZ well, the calculated maximum assembly length is 12.5 m. Lifting assessment were made to the single-trip multizone assemblies when run in holes (RIH) using a crane. The project team worked closely with the service contractor to optimize lower completion schematic plan and ensure the assembly length did not exceed this limitation (Figure 10).

Figure 9 - Hoist System Using a Crane in the Main Barge

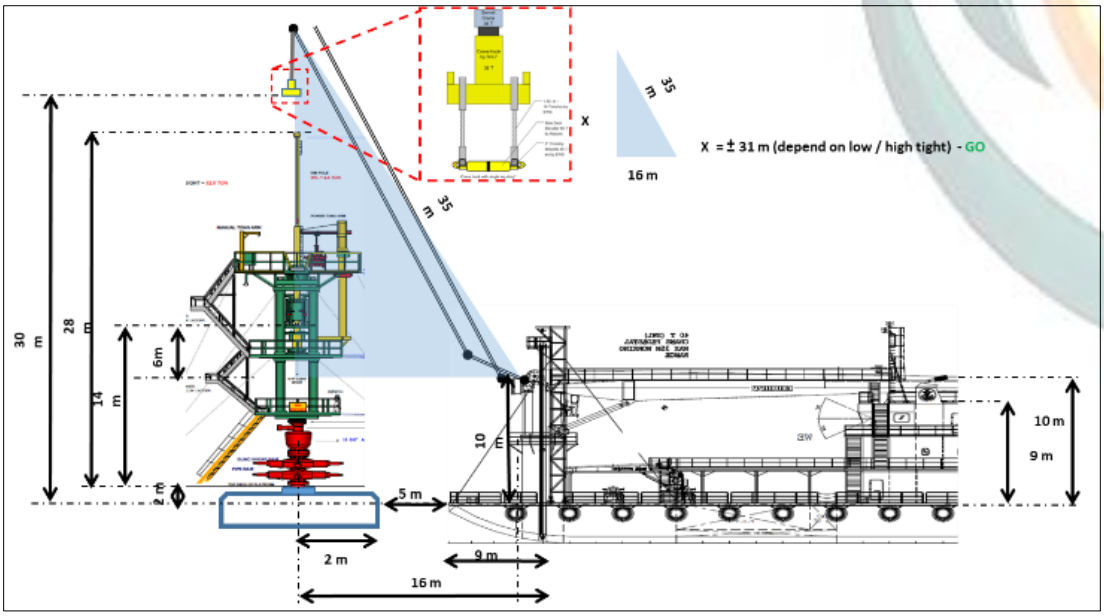

Figure 10 - Crane Lifting Assessment.

Well Control. Well monitoring activities on the trip tank is mandatory during the rigless operation to achieve a successful well control risk mitigation plan. Furthermore, swamp environment and weather condition are to be considered while monitoring trip tank to get accurate well control reading. The trip tank was constantly monitored to ensure the hole was always filled during RIH, and a dedicated crew was assigned to monitor the fluid level closely every five minutes. In addition to that, three sensors were installed to monitor the fluid level accurately and record the average trip tank level every two to three seconds.

Figure 11 - Sensor Display on Trip Tank Connected to the Supervisor Room.

As part of the completion program, the lower completion assembly and Tubing Convey Perforation strings will be overlapped across the Blow-Out Preventer Rams, where the shear ram is unable to shear through the assembly simultaneously, creating a unique well control scenario as below :

- Shearing Period (SP) –During the running of the work string to RIH outer string assembly, the annular or shear rams acted as the mechanical barrier and provided a typical well control setup.

- Non Shearing Period (NSP) – During make up and running of the 7" MST assembly (washpipe, screen, etc) on Work Basket and Tubing Convey Perforation assembly.

Completion and Stimulation Strategies

General Elastomer and Metallurgy Selection The proper elastomer material and metallurgy selection are important to prolong the durability of the well and minimize production restriction. These can help prevent or minimize the possibility of premature erosion and corrosion. Based on the well conditions, the well produces gas with no H2S and less CO2 content; hence, it should have low potential for corrosion. Low alloy steel was selected as the equipment metallurgy to provide adequate service.

Equipment Pressure Ratings. Equipment pressure rating are directly related to the formation pressure and expected maximum pressure during gravel pack operation. As HRWP was selected as the treatment method for Well TN-AAXYZ based on the required packing factor and sand properties. For Well TN-AAXYZ, 6 bpm was required to achieve a HRWP, which translates to not more than 3,800 psi to slightly frac open the formation sand. Based on this justification, all downhole equipment chosen was rated to 5,000 psi burst and collapse pressure at minimum.

Gravel Pack Packer. The gravel pack packer is the top-most packer that provides anchoring for all the gravel pack assemblies and isolate the top zone. The selection of gravel pack packer depends on the compatibility of MZST service tool used. The selected packer comes with an internal premium thread that allows for the heavy hang-weight capability, soft release and secondary release.

Screen. In reference to the selection of the proppant size, 12-gauge wire wrapped screen (WWS) was determined as the appropriate size to filter the induced proppant. The smallest size of a 20/40 proppant is 16.5 gauge. Thus, 12 gauge is sufficient to hold off the proppant from bypassing the screens opening. For a cased hole gravel pack, the screen is put under a relatively less torturous conditions during RIH compared to open hole gravel pack, in this case centralizer installed on the screen assembly.

Sump Packer. The sump packer is the bottom-most packer in a gravel pack system. It acts as a sump for the gravel and the gravel pack assemblies. It also provides the datum point for the equipment gravel pack assembly's correlation. Thus, it is vital for the packer to be set at the correct depth. The sump packer can be run via wireline or drillpipe correlated through gamma ray log.

The TN-AAXYZ was selected as gravel pack well candidate as a trial well which technically all zone properties meet the MZSTGP requirements. TN-AAXYZ well had been drilled with a rig and suspended with 7" casing cemented. There are two perforation zones in this well, and both of the perforation are separated by a distance of 109 m, with a maximum inclination of the well 41°.

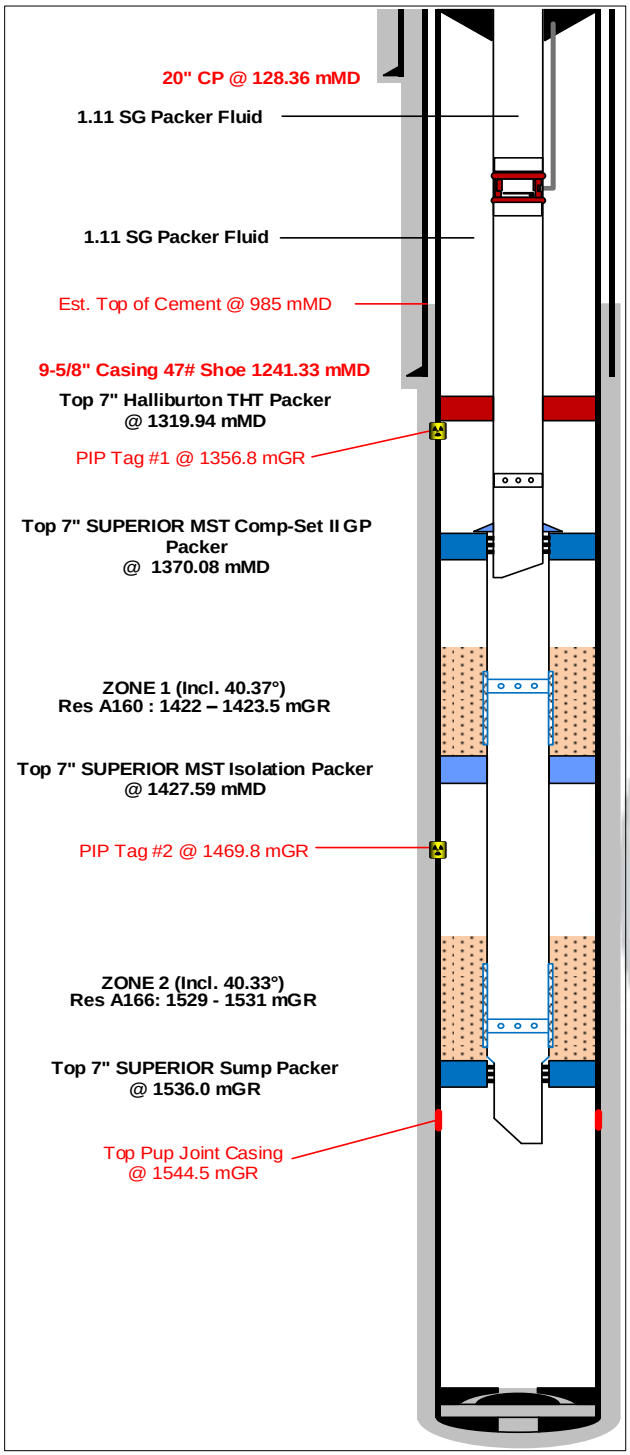

Figure 12 - TN-AAXYZ Well Diagram.

Proppant placement into the wellbore was carried out in the two perforation zones in sequence without any technical and safety issue to the whole pumping process. Normal screenout pressure trend achieved for both zones as an indication of proper proppant placement.

The sequence of MZSTGP rigless operation is as follows:

1. Site and wellhead preparation.
2. Barge setup and arrangement to the platform.
3. Rigging up the HWU supported by the wellhead and guy wires on the dedicated piling at the platform area.
4. Perforation of the well using the TCP method with 4-1/2" gun.
5. Perforation deburring.
6. Wellhead and BOP cleaning.
7. Make Up and Run in Hole gravel pack assembly using service tool, which is followed by pumping proppants for each zone.
8. Make Up and Run in Hole upper completion, production tubing, and accessories such as mule shoes, production packers, and Downhole Safety Valves (DHSV).
9. Pressure test 4,000 psi for integrity of the tubing and all equipment.
10. Inflow test DHSV with 2,500 psi pressure difference.
11. Rig down the HWU and BOP units, followed by the installation of the Christmas Tree.
12. End of the completion activity.

3 Result and Discussion

The well was completed as per planned without any issues. Service tool movement for each zone occurred smoothly without any difficulties. No excessive overpull was observed when the tool was picked up from circulating to reverse, reverse to dump seal position, and during POOH. Screenout was achieved as per the design with clear indication of blank and screen coverage. The results of the sand pumping process in the two perforation zones (Fig. 14) are summarized as in Table 1 below.

TABLE 1

GRAVEL PACK STIMULATION RESULT

Zone of Perforation	Pack Factor (lb/ft)	Blank Coverage Length (m)	Total Sand in Blank (lbs)	Perfo Interval (m)	Blank Length (m)	Screen Length (m)
1	146	3.4	99	1.5	26	11
2	345	7.9	231	2	89	11

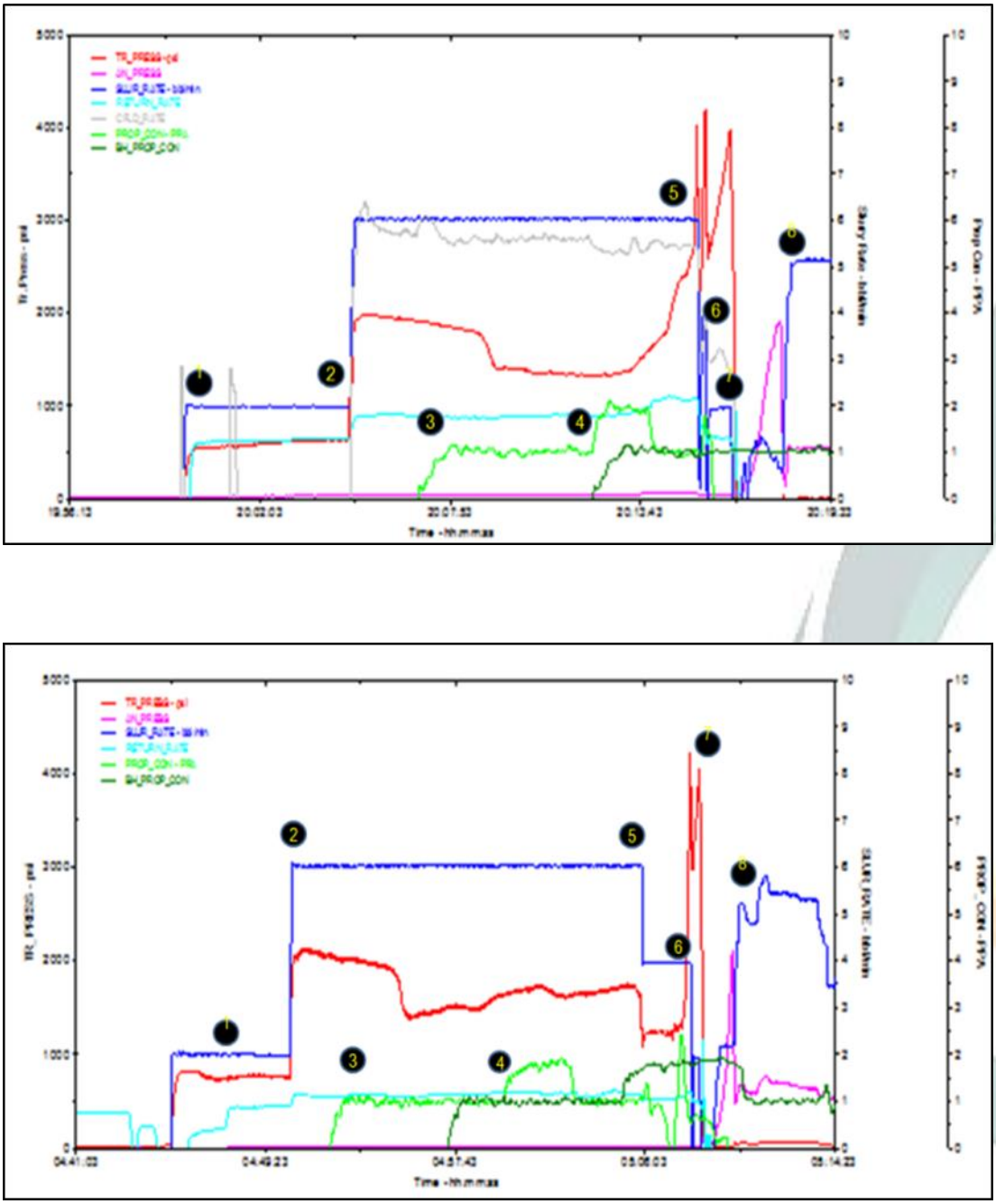

Figure 14 - Pumping Chart zone #1 (top) and zone #2 (bottom).

4 Conclusion

Multi Zone Single Trip Gravel Pack (MZSTGP) with HWU system was successfully executed with no HSE issues and incident record. This project resulted in significant savings of approximately 37% or equivalent to half a million USD, obtained from the comparison of the time and operating costs of MZSTGP (Figure14). Even though the operating time is longer, the total well cost with HWU is less than with conventional rig.

The combined effort of both parties enabled the team to deliver first-time operation towards success despite the presence of risks. Proper planning and execution combined with effective communication between both parties has enabled us to claim this milestone of being the first in the world to run 7" MZSTGP with a HWU in a swamp area. This will certainly bring benefits to Pertamina Hulu Mahakam in creating a cost-effective MZSTGP well. As a way forward, this method will be implemented in offshore areas to gain more benefits and cost savings.

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