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Pioneering Application of Plasma Spray Coatings to Improve the Erosion Resistance of Rod Based Wedge Wire Screen

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Abstract

Managing sand production has been a common problem and one of the most difficult challenges within the oil and gas industry. Various techniques are available to control sand production such as downhole sand screens. More than half of the wells in Malaysian fields are completed with downhole primary sand control or require sand management throughout their lifetime. To further aggravate the issue, most primary sand controls installed have suffered from failure after an extended period of production due to unacceptable high pressure drop in the near wellbore area which causes the screen to lose the ability to retain the formation sand particles. There are four (4) common mechanisms that can lead to the screen failure which include plugging, corrosion, erosion, and mechanical deformation. Erosion occurs when the formation particles hit the screen surface with high velocity or by continuous production through the screen openings. Operators are often compelled to rely on thru-tubing metallic sand screen to reactivate the idle wells back into production. However, most metallic sand screens suffer from sustainability issue due to excessive erosion especially for gas wells. Most operators have shifted their focus to maximize the screen lifetime against erosion, which consequently leads to the development of a novel sand screen design where an inventive coating consists of ceramic or hard metal amalgamation was applied by plasma spraying technique on the screen (i.e., outside surfaces facing the formation) to reinforce its resistance against severe erosive environment. An extensive development and verification program was conducted to select over 50 possible coating combinations, guarantee predefined slot size, assess corrosion resistance, and ascertain mechanical integrity of both the coating and screen. The technology has been considered and applied in Field A, offshore Borneo Island as remedial sand control due to its superior durability and resistance compared to metallic sand screen.

Extensive technology hunting had been conducted by the operator to identify new erosion resistant thru-tubing sand screen for gas well application. As part of the overall project requirement, test facility was built by the Service Partners that consists of a flow loop testing designed to simulate accelerated erosive downhole condition with the combination of high flowrate and volume-controlled particle coalesced into an acceleration tube. The screens were tested for 60 hours at maximum velocity of 18 m/s during liquid

erosion test and for 48 hours at maximum velocity of 80 m/s during gas erosion test. Rigorous analysis was conducted focusing on among others optical criteria, mass loss and sand retention tests (SRT) before and after the erosion test to verify the functionality and validate its performance prediction prior to the actual field application. Velocity calculation was also conducted using in-house and commercial software to adjudicate the design limit, to set the target gas rate for the pilot wells and establish the well unloading procedure as guidance for offshore personnel. Pilot field trials have been designed to demonstrate screen installation, risk mitigation and sustained production. Dual-pot sand filter (DPSF) and online sand sampler (OSS) was deployed as additional assurances to safeguard topside integrity, to closely monitor the sand production at surface and collect any sand grains larger than the screen slot sizing throughout the well unloading sequence.

Close inspection on both erosion tests indicated no significant wear or slot size widening of the coated screen samples as compared to the uncoated screen samples that show severe erosion with slot size increases more than doubled in some places. The coated screen samples show the equivalent sand retention capabilities before and after the erosion tests, while the uncoated screen sample subjected under the same conditions lost its ability to retain sand. During field trial, the screen was successfully installed using nipples plug via slickline to revive the idle wells back to production at a lower total cost without HSE related issue and production gain beyond the initial target. Actual field results supported by the extensive laboratory testing presented herein, demonstrate the inherent benefit of plasma spray coatings ensuring mechanical integrity and durability of sand screen in highly erosive environment. Teardown analysis will be conducted to investigate the performance prediction, authenticate erosion resistance of the sand screen bottomhole assemblies (BHA) and document the findings for future improvement.

Introduction

For most sandstone reservoir's, sand production remains as a significant threat for most operators except for consolidated sandstone with high strength. Oftentimes, for weak or unconsolidated sandstone formation's, it is imminent that the reservoir will produce sand in production stages even at small drawdown rates. To exacerbate the issues, sand can be produced at significant and uncontrollable quantities which may lead to serious complications, including restrained production, loss of the well due to sand fill in the wellbore and/or excessive erosion and/or maintenance to both downhole and surface equipment. Sand production is usually attributed to rock or formation failure, which can be further associated to several contributing factors. Reduction in pore pressure due to depletion may result in rock failure due to changes in rock stresses. Uncontrolled drawdown's which occur above the critical drawdown pressure may lead to undesirable sand production. Thus, most operators will deploy the strategy to limit the production or drawdown imposed at the sandface to avoid sand production. Sand production may also occur in reservoir with high fluid viscosity due to viscous drag forces. Changes in flow phases such as an increase in water production rate can result in sand production due to the increase in drag forces for mobilizing sand grains. Many literatures have demonstrated common field observations that the initiation of sand production often corresponds with water breakthrough (Veeken et al., 1991; Bruno et al., 1996). Therefore, deployment of sand control is inevitable for most weak or unconsolidated sandstones as water production is expected in the later stages of field development, especially for those with plans to implement water injection as improved oil recovery (IOR).

To contain sand production downhole, most operators will adopt sand control techniques which include both passive and active sand control techniques. Passive sand control methods include drawdown control, oriented perforation, and selective perforation while active sand control techniques involve installation and completion of downhole sand control at sandface such as stand-alone sand screens, expandable sand screens, gravel packing, frac-and-pack and chemical consolidation. Passive sand control measures are usually coupled with stringent surface sand monitoring as they do not have barriers to control sand production downhole. On the other hand, comprehensive studies are required for primary sand control selection, which are often based on several criteria such as particle size distribution, sorting coefficient, uniformity coefficient, reservoir fluid and characteristics, etc. Inappropriate sand control selection, faulty installation, and improper bean-up procedure can lead to failures in active sand control, resulting in severe sand production which can jeopardize the integrity of production facilities and lead to well bean-down or shut-in. In cases with primary sand control failure, most operators will adopt thru-tubing remedial sand control as it is considered more economical by eliminating the necessity of conducting well workover.

Thru-tubing remedial sand control techniques are widely applied in marginal wells with limited reserves or existing wells with sand production where workover or sidetrack is not cost-effective. Over the past decades, thru-tubing remedial sand control methods have been deployed, with rather mixed success. A highly erosive environment is present in smaller tubing size's due to the increase in flow velocity thus further aggravates the challenges in deploying thru-tubing remedial sand control techniques. Thru-tubing metallic screens are often favored due to its ease for installation and lower cost. Nonetheless, such metallic screens will suffer from reliability and sustainability issues due to plugging or erosion, which usually impel operators to carry out frequent well intervention for screen change-out. Numerous studies have identified that the failure of thru-tubing metallic sand screens is usually attributed to its susceptibility to erosion (Sidek et al., 2017).

Due to the susceptibility of metallic screens to erosion, aggressive effort has been concentrated in identifying and selecting materials with more durability for screen manufacturing, leading to the maturation of the use of plasma sprayed coated screens as direct replacement for metallic materials with the aim to withstand highly erosive environments. Ceramic coated (plasma sprayed) rod-based wire wrapped screens has been selected due to several advantages. First, the screens with ceramic coatings offer better erosion resistance under highly erosive environment in gas wells. Besides, the rod-based design (due to the absence of base pipe) promotes better hydraulic efficiency by reducing flow path velocity and eliminating 'hotspots' presence by increasing overall inlet area to flow.

Plasma Spray Coatings

Thermal spraying method is deployed to coat the rod-based wire wedge screens through a process which uses a hot plasma jet to melt powdery materials and apply them to a solid surface. The molten particles will then harden on the surface and form a hard coating with little porosity. No chemical reaction occurs between the base materials and the coating as the adhesion of the coating is purely mechanical.

Several steps are required to coat a wire wrapped screen with plasma spray coatings. First, the screen is sandblasted to provide a defined surface roughness with the aim to enhance the mechanical bonding between the two composites. Subsequently, a thin bonding layer is applied by thermal spraying, which serves as the intermediate layer to further improve the adhesion of the functional layer. Erosion-resistant main layer, which consist of ceramic or hard metal amalgamation, is then applied via the same thermal spraying method. Finally, a liquid sealer, which will be hardened subsequently under thermal treatment, is then applied to fill up the pores of the sprayed layers, tremendously improving the corrosion resistance of the composite. Fig. 1 schematically shows the coating steps, layers, and final product (Ochmann et al., 2021).

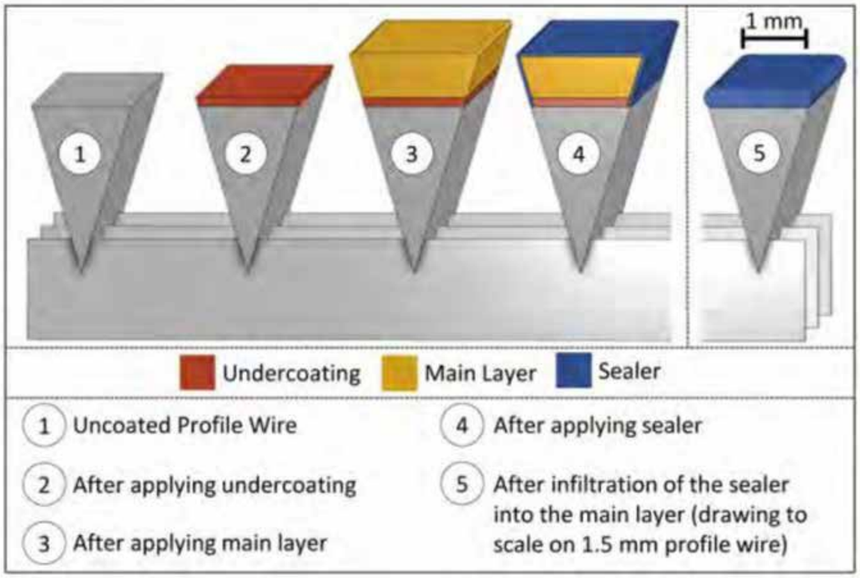

Figure 1—Schematic visualization of coating steps, coating layers and the final product.

The coating changes the geometry of the slots as it slightly reduces the slot size and creates a less sharp slot opening. Thus, desired slot widths of the final products are manufactured by adjusting the precise process parameters of the thermal spraying choosing the correct initial slot width of the wire wrapped screens.

To conduct erosion testing in laboratory setting as part of the tehcnology selection process, test facility was built by the Service Partner, which consists of a flow loop testing designed to simulate accelerated erosive downhole condition with the combination of high flowrate and volume-controlled particle coalesced into an acceleration tube. The screens were tested for 60 hours at maximum velocity of 18 m/s during liquid erosion test and for 48 hours at maximum velocity of 80 m/s during gas erosion test. Rigorous analysis was conducted to verify the functionality and validate its performance prediction prior to the actual field application. Close inspection on both erosion tests indicated there was no significant wear or slot size widening of the coated screen samples as compared to the uncoated screen samples that show severe erosion with slot size increases more than doubled in some places. The coated screen samples show the equivalent sand retention capabilities before and after the erosion tests, while the uncoated screen sample subjected under the same conditions lost its ability to retain sand.

Candidate Screening and Selection for Pilot Testing

Field A is located approximately 140 kilometers northwest of Bintulu, Sarawak in Malaysia. Credits to the exploration effort in the year of 1969 and 1970, it was first discovered as stacked clastic reservoirs with an area extent around 600 km^2. The field consists of an alternating sand-shale sequence with producing gas bearing interval in which the gas is trapped in two-echolon anticlines NE-SW fold axes. The drive mechanism for Field A is depletion drive with weak aquifer support. The contamination is low as the field has been producing less than 2 mol% CO_2 and 0.5 ppm H_2S contents ever since the first gas production. Figure 2 illustrates the location and the geological cross section of the reservoir structure for Field A.

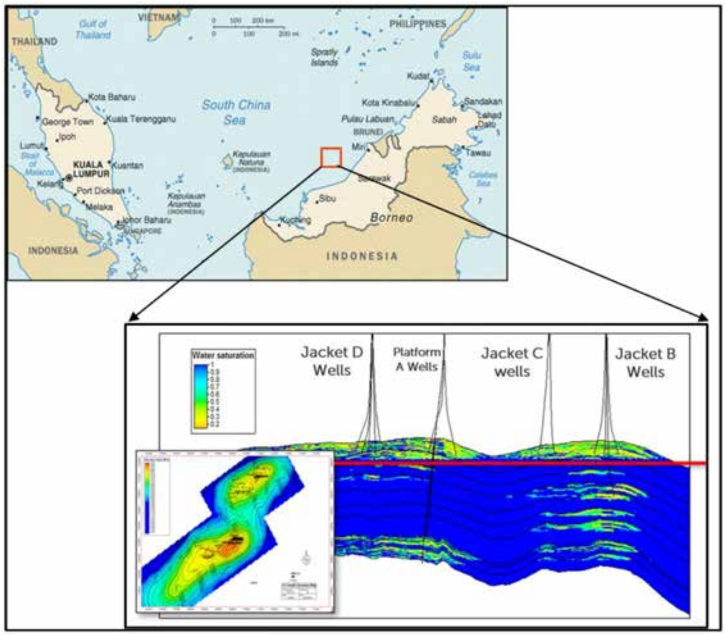

Figure 2—Location and geological cross section of the reservoir structure for Field A

Well X has been selected as one of the pilot candidates for the ceramic coated rod-based wire-wrapped screens. Well X is a dry gas well with technical potential of around 20 MMscf/d but was idle for three years due to sand production and the lack of mature erosion-resistant thru-tubing sand screen technology for well reactivation. The well was initially completed with horizontal open-hole gravel pack (OHGP) in July 2005 with first gas production in May 2006. However, after years of production under depletion drive, the reservoir pressure declined significantly. The reduction in reservoir pressure induced changes in rock stresses and diminished the critical drawdown pressure. Sand production issues became apparent and turned into one of the major challenges in field management. Well X suffered from the failure of downhole primary sand control with significant amount of sand (with proppants) produced and recovered at wellhead desander accumulator (2 barrels) before it was closed in Aug 2018. Figure 3 shows the sand collected post flushing of wellhead desander in August 2018. The ceramic coated rod-based wire wrapped screen (2 joints of 15-ft each) was then successfully installed in mid-September 2020 using slickline package and the screen was hung above perforation interval using a nipless plug.

Figure 3—Significant amount of sand with proppants (2 barrels) was collected during desander flushing in August 2018.

To further understand and define the operating limit of ceramic coated wire wrapped screens, downhole erosion velocity study and modeling were conducted. Both annular velocity (between screens and tubing) and velocity within base pipe of the screens have been studied and examined. The annular velocity was calculated using equivalent hydraulic area and multiphase flow correlations. High annular velocity and base pipe velocity were expected as Well X was producing at high gas rate. Therefore, sensitivity analysis has been conducted to study the impact of gas flow rate on velocity. To limit the annular velocity at 40 ft/s (based on internal guideline and recommendation) and erosion rate based on screen design limit, the well was capped at gas flow rate of 10 MMscf/d. The screens will be retrieved and replaced after three-month pilot testing. Teardown investigation will be conducted to study the screen erosion.

Pilot Testing of Rod Based Wedge Wire Screen with Plasma Spray Coatings

Post successful screen installation via slickline, temporary surface assurance package was mobilized to offshore to provide barriers and safeguard production facilities for any sand production as initial sand surging was expected during initial stage of well flowback. Dual pot sand filter (DPSF) was tied in at the downstream of existing wellhead desander at flowline using temporary piping. Since the wellhead desander is designed to filter the sand effectively down to particle size of 10 to 20 microns at minimum operating flow rate of 10 MMscf/d, dual pot sand filter equipped with 50-micron filters will serve as the secondary barriers for removing the produced sand during gradual bean-up stage (Figure 4).

Figure 4—Dual-pot sand filter was mobilized and tied-in at flowline using temporary piping as part of temporary surface assurance package during initial well flowback.

To detect the sand production instantaneously, the signal response from the existing permanent acoustic sand sensors was monitored closely. Furthermore, online sand sampler was mobilized to site to enable sand detection and quantification owing to the maturation in gas well sand sampling technology in the past recent years. The online sand sampler was used to collect physical sand samples from the flowline by connecting to the sampling point. Figure 5 illustrates the online sand sampler (OSS) setup at wellhead area (upstream of the wellhead desander) by connecting to the sampling point.

Figure 5—Online sand sampler (OSS) setup at wellhead area (upstream of the wellhead desander) to collect physical sand samples from the flowline by connecting to the sampling point.

The sampler was initially connected to the sampling point downstream of the dual-pot sand filters to ensure there was no sand carryover downstream to the production facility. It was then relocated to the upstream of the wellhead desander for collecting any sand grains larger than the screen slot sizing throughout the well unloading sequence to further evaluate the efficiency of downhole screen in controlling the sand production downhole. Figure 6 below shows the schematic diagram of the flowback setup for Well X which include dual-pot sand filter and online sand sampler as part of temporary surface assurance package.

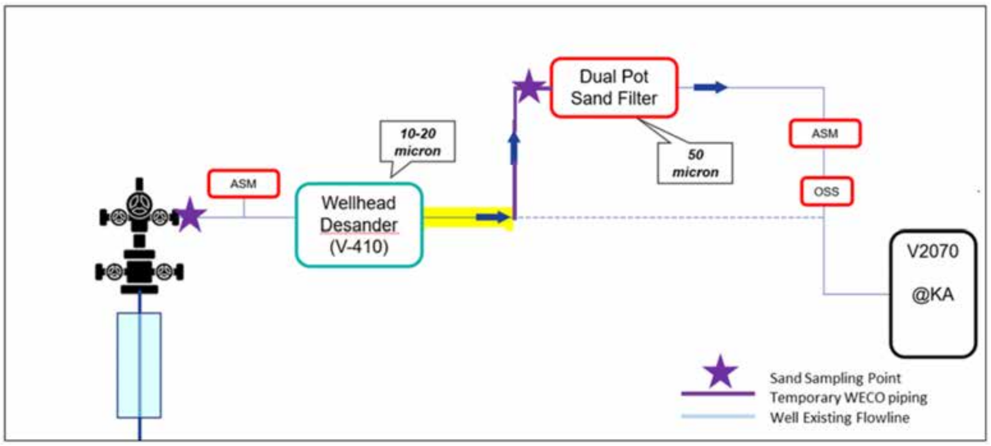

Figure 6—Schematic diagram of the well flowback setup which include dual-pot sand filter (DPSF), online sand sampler (OSS) and acoustic sand monitoring (ASM) for safeguarding topside facilities.

Well X was opened to flow at 7 MMscf/d on 26th July 2021 at the smallest flow control valve (FCV) opening size and was monitored closely for sand production for a period of three days. During the initial stage of flowback, minimal sand was recovered at dual pot sand filter as there might be some remnant sand present in the wellbore or flowline. Well X was then beaned up gradually to achieve the target rate of 10 MMscf/d. Table 1 below records the FCV size, gas flow rate, sand amount collected at DPSF and estimate sand count throughout the monitoring period.

Table 1—FCV size, gas flow rate, sand amount collected at DPSF and estimate sand count throughout the one-week monitoring period.

Date	Max FCV size (%)	Gas Flow Rate (MMscf/d)	Sand collected at DPSF (kg)	Estimated Sand Count (ppMMscf)
26-Jul	2.5	7	0.02	0.038
27-Jul	2.7	7	0.02	0.029
28-Jul	2.9	7	0.01	0.012
29-Jul	6.7	8	0.02	0.026
31-Jul	12.8	10	0.03	0.035
1-Aug	12.8	10	0.01	0.015

Sand samples were collected from the online sand sampler which located at the upstream of wellhead desander. Collected sand samples (Figure 7) were sent to laborarty for laser particle size analysis (LPSA) for particle size distribution (PSD) to determine the screen filtration efficiency and integrity. PSD of the collect sand samples indicated that the downhole screen is functioning as effective sand control as the sand produced at surface was within the screen slot sizing tolerance. The flowback campaign with temporary surface assurance package was concluded after one-week monitoring period. Well X was then opened to flow into production facility through the permanent wellhead desander only after rigging down the dual pot sand filter package and reinstating the well flowline. The screens will be scheduled to retrieved after three months of pilot testing. Teardown investigation will be conducted to observe for any erosion which might affect the screen efficiency.

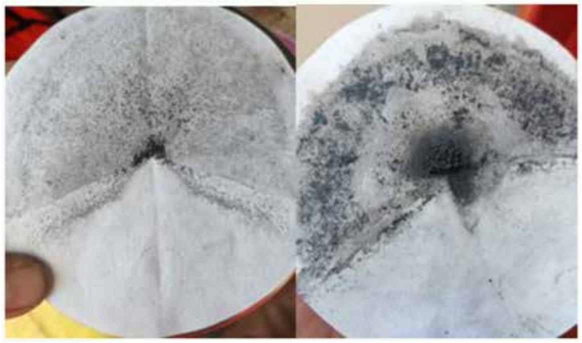

Figure 7—Sand sample collected from the online sand sample (OSS) located at the upstream of the wellhead desander after being drained and filtered using filter paper.

Conclusion and Recommendation

1. Ceramic coated (plasma sprayed) rod-based wire wrapped screens offer better erosion resistance under highly erosive environment in gas wells. Its application has been proven successful after the first pilot trial in the world.
2. In the scenario in which screens are limited to be installed high above perforation interval, it is highly recommended to conduct studies on the downhole velocity (annulus and base pipe) in the future application of thru-tubing sand screens to ensure the erosion velocity is within tolerable limit. Such study will help to identify the maximum flow rate based on screen design limit.
3. Temporary surface assurance package which consists of dual-pot sand filter as sand removal system together with sand monitoring equipment such as acoustic sand sensors and online sand sampler is highly recommended during initial well flowback to safeguard the production facility from initial sand surging during unloading and to collect adequate samples for screen filtration efficiency evaluation.
4. Prudent well open-up and bean-up procedure is crucial in avoiding sand surges which will jeopardize the integrity of screens and may lead to screen failure. Well with thru-tubing screen installation should be given adequate time to flow at lower rate with lower choke size prior to beaning up to achieve target rate.
5. Ceramic coated (plasma sprayed) rod-based wire wrapped screens will be retrieved after three months of monitoring. Teardown inspection will be conducted to identify any erosion patterns, which may lead to further design improvement. Ceramic coated wire wrapped screens will be installed in two other wells in the same field to further identify the screen operating limit and longevity as part of the pilot program.

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Nomenclature

ASM =Acoustic sand monitoring
CO_2 =Carbon dioxide
DPSF =Dual-pot sand filter

FCV	=Flow control valve
ft/s	=feet/second
H_2S	=Hydrogen sulfide
HSE	=Health, safety and environment
IOR	=Improved oil recovery
LPSA	=Laser particle size analysis
m/s	=meter/second
OHGP	=Open-hole gravel pack
ppm	=Parts per million
ppMMscf	=Pound per million standard cubic feet
PSD	=Particle size distribution
scfd	=Standard cubic feet per day
SRT	=Sand retention test

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