A CRITICAL REVIEW OF SAND CONTROL DESIGN FOR SAGD WELLS

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A Critical Review of Sand Control Design for SAGD Wells

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ABSTRACT

Several sand control techniques have been used in SAGD wells in Western Canada. For most projects, slotted liners have been the sand control of choice for its economics, ease of use, and acceptable performance. Careful design of the slot geometry is crucial to maintaining long-term wellbore performance but is not an easy task in formations with high fines content and other challenging characteristics, such as in Grand Rapids or shoreface at the upper member of McMurray. The primary objective in the design of sand control is to minimize the production of sand and maximize the retained permeability in the liner's vicinity by allowing the production of any mobilized fines, avoiding extreme pressure drops by minimizing the curvature of flow streamlines around the slots, and avoiding the plugging of slots over time. Design practices for sand control in SAGD wells are currently based mostly on Particle Size Distribution (PSD) and the fines (<44um) content. Where designers focus principally on retaining sand rather than maximizing the retained permeability in the liner's vicinity, there is an increased risk of underperforming completion designs. However, long-term well performance requires a reasonable tolerance for solids production. This paper provides a critical review of existing design criteria and the experimental testing and techniques for assessing the sand control design for SAGD production wells. It reviews the mechanisms which cause sand production and fines migration in relation to the PSD of oil sands and the formation clay and silt content. In addition, the paper presents field failure cases from the literature and examines the common problems with different types of sand control. Finally, practical recommendations are presented to further improve the sand control experiments and the current design criteria to achieve higher productivity index, lower skin buildup, and greater durability of sand control screens.

KEYWORDS

Oil sands, Sand control, Plugging, Sand production, SAGD, Design criteria

INTRODUCTION

Alberta possesses about 170 billion barrels of heavy oil reserves from oil sands (ERCB, 2011). The oil sand reserves have been exploited using two production methods: mining and in situ enhanced oil recovery. The area of surface mineable oil sands is only about 3% of the total oil sands area, thus deeper resources must be recovered by in situ techniques (CAPP, 2011).

Steam Assisted Gravity Drainage (SAGD) is the main thermal technique for in situ heavy oil production in Canada. This technique employs two horizontal wells. High-pressure steam is injected into the upper wellbore, known as the injection well, to heat the heavy oil and reduce its viscosity. The heated oil and condensed water drain into the lower wellbore to be pumped out (Guo, 2014). As the steam chamber develops in the reservoir, it transfers its latent heat to the cold bitumen. As the bitumen viscosity reduces by the higher temperature, the heated oil together with the condensed steam drain into the lower production well.

SAGD wells are supported against collapse by the installation of screen liners in the well, which are called Sand Control Devices (SCDs). These screens are designed to (1) control sand production while allowing the flow of reservoir fluids into the wellbore, and (2) allow the discharge of fine materials to avoid the plugging of screens and pore spaces behind the screens. Slotted Liner (SL) and Wire-Wrapped Screen (WWS) are two common SCDs in SAGD wells.

SAGD projects have high Ongoing Operating Expenses (OPEX) with 65–75% of total OPEX attributed to steam generation (Mohajer et al., 2010). Moreover, completion performance-related issues in thermal operations such as liner failure, excessive plugging, well cleaning, damage to surface facilities, and limited production rates are costing the Canadian oil industry a significant amount of time and money. Due to the lack of certainty in the performance assessment of wellbore completions in terms of flow and sand control, the industry often opts for conservative decisions. Examples include using expensive completions, such as Premium Screens (PSs), to provide more Open to Flow Area (OFA) and improved sand control.

With recent volatility in oil prices, avoiding unnecessary capital costs and reducing the operating costs is critical for Alberta to remain competitive in today's oil market. This urgent need could be met by optimizing the wellbore completion design and reducing the wellbore intervention costs.

A better understanding of completion performance would help to avoid expensive remedies. It also helps in designing the common completions (such as SLs) in a smarter way to improve their performance and to avoid expensive alternatives.

This paper provides a critical review of SCD design for SAGD projects, outlines the common procedure for SCD design, and discusses the existing challenges and considerations in sand control and flow capacity performance of the SCDs. The paper also examines the failure cases of SCDs, which have been reported in the literature. A discussion is also provided on further possible improvements in the SCD design and evaluation.

SAND CONTROL DEVICES

Common SCDs for SAGD applications are SL and WWS. Precise Punched Screen (PPS) is also used in some cases. Recently more expensive and sophisticated SCDs have been considered which are categorized as PS.

Slotted Liner is a pipe with multiple longitudinal slots spread along the length and across the circumference of the pipe. It is the most popular SCD due to its reasonable cost and mechanical integrity. However, it provides OFA of only about 2-3%. Larger OFAs are not accessible as slot numbers should be limited to provide the required mechanical integrity (Xie et al., 2007; Xie and Solvoll, 2009).

The OFA provided by SLs exceed the production requirement of SAGD provided the slots are kept open in long-term amid corrosion, plugging, and scaling. Coated SL has been recently introduced to reduce corrosion and scaling and to keep the slots open for longer time. Initial studies have shown promising results (Fermaniuk et al., 2015). Further studies are being conducted to evaluate the efficiency of these new products (Fermaniuk et al., 2015).

Slotted Liners have been produced with Straight Cut (SC), Keystone Cut (KC) and Rolled-Top or seamed (RT) profiles (Fig. 1). Different patterns including Horizontal Slot (HS), Line Slot (LS), Staggered Slot (SS) and Gang Slot (GS) have been used (Fig. 2). However, SLs with SS pattern and RT profile are more common in SAGD operations due to their reasonable cost, simple mechanism/design, and mechanical strength (Fermaniuk, 2013).

Until recently, SL could not be manufactured with the very small apertures that could be achieved by WWS manufacturing methods. Further, historical slotted liner was considered a crude and low quality product. However, recent advancements in slot manufacturing tolerances have resulted in the ability to manufacture slots as small as 0.006" (Kaiser et al. 2002) and provide for precise slot aperture openings which match or surpass WWS slot openings (Fermaniuk, 2013).

Wire-Wrapped Screen consists of a base pipe perforated with holes or slots in its sides with a triangular wire wrapped around it. The wraps of wire are carefully spaced, with the distance between wraps providing the sand control aperture. Because the aperture is continuous and long, it provides more OFA (7-12%) than SLs. It is the second most popular SCD for SAGD applications after SL. While the base pipe is manufactured from common liner material (K55, L80, etc), the wrap wire is typically stainless steel.

Precise Punched Screen is composed of a perforated base pipe that provides the mechanical integrity, and a punched shroud which provides the sand filtration. It has been used in few SAGD projects.

Premium Screens are more complicated than SL, WWS, and PPS. They have a single layer or multiple layers of woven wire mesh, sometimes sintered, forming a resilient filter. The filter is usually mounted on a perforated base pipe. These devices could provide high OFA (25 to 40%) and high mechanical stability. However, they demand high costs compared to SL, WWS, and PPS. The current drop in oil price and urgent need to optimize the production costs reduces the interests to use these completions for SAGD operations.

DESIGN OF SCD

No unique procedure exists for wellbore completion design. A simplified procedure (Fig. 3) is usually followed in the industry (Weatherford International, 2010; William et al., 2014; Mahmoudi et al., 2016b). The design procedure may go through different decision loops and is revised several times (Fig. 3). However, experience and judgment of the designer is usually heavily leveraged during the design process.

As outlined in Fig. 3, one needs to consider several factors including sand control, flow capacity, mechanical integrity, erosion/corrosion, fluid program, and reservoir management for a successful completion design.

PARTICLE SIZE DISTRIBUTION (PSD) ANALYSIS

Cumulative PSD diagram is commonly used as the main input in SCD design. The cumulative PSD shows what weight percent of a sample is larger than a particular particle size. Cumulative display of PSD allows fitting of a single curve to discrete data and interpolation to read off certain values of the distribution. In practice, only certain points (D values) of the PSD curve are used for SCD design.

There are several techniques to determine the PSD such as Sieve Analysis (SA), Laser Diffraction Particle Size Analysis (LPSA) and Dynamic Image Analysis (DIA) (Mahmoudi et al. 2015).

Sieving is considered to be the most appropriate method of PSD analysis for screen design applications (Fermaniuk, 2013). However, during the sieving, fine particles can adhere to the surface of larger particles (Zhang et al., 2014) and affect the measurements. Measurements could be also affected by the tendency of grains to agglomerate, density, and electrostatic charging (Gupta et al., 1975). Sieve analysis represents the second smallest dimension of the grain due to the way particles orient themselves to pass through the sieve openings. Sieving requires samples larger than 10 g. It could measure only down to 45 μm (Weatherford International, 2010) or 37 μm (Zhang et al., 2014). Therefore, it does not provide enough data for fines (<44 μm).

Laser Diffraction Particle Size Analysis is a common technique for determining the PSD of oil sands. It determines the PSD by measuring the variation of scattered light intensity. This method tends to report different sizes for non-spherical particles with the same equivalent diameters (Ballard et al., 1999; Zhang et al., 2014). Moreover, for fines and clay particles, this method is sensitive to the suspending media (Zhang et al., 2014). Laser Diffraction Particle Size Analysis can measure sizes down to 0.4 μm (Weatherford International, 2010) or 0.5 μm (Zhang et al., 2014), and it requires much less sample than the same for sieving (<1 g) (Zhang et al., 2014).

Dynamic Image Analysis is based on analyzing the image of individual particles to build conventional PSD curve. Mahmoudi et al. (2015) showed the accuracy of DIA for PSD analysis of oil sands sample from McMurray Formation. In comparison with sieving and LPSA, DIA offers more detailed data (such as Martin's diameter, Feret's diameter, and projected area diameter) to describe particle dimensions. The extra data could be used to understand the grain shapes and more completely characterize the target sand.

Grain shape is not commonly considered in SCD design. However, experimental studies, which have led to the current criteria, have used real sand grains.

One of the difficulties to include the grain shape in SCD design is the grain shape quantification. Historically, grain shape factors (such as angularity and roundness) have been classified qualitatively based on charts or scales (Powers, 1953; Krumbein and Sloss, 1963). Recently, by the advent of image analysis sensors known as size and shape analyzers (e.g., *QICPIC*-Sympatec and *CAMSIZER*-Retsch), particle shape factors could be quantitatively described.

Aspect ratio, convexity, and sphericity are common parameters to define the grain shape (Mahmoudi et al. 2015). Mahmoudi et al. (2015) studied samples from two wells in McMurray Formation at different depths using *QICPIC* and found similar values for the grain shape parameters for all studied samples.

Due to the limited data available to date, a comprehensive study is required to find the variation of grain shapes in oil sands in Western Canada before further studies to include the grain shape in SCD design criteria.

CRITERIA FOR SCD DESIGN

Different numerical (Mondal et al., 2011), analytical-statistical (Chanpura et al., 2011, 2012 and 2013), and experimental (Coberly, 1937; Rogers, 1971; Suman et al., 1985; Gillespie et al., 2000) studies have been performed to develop criteria for SCD design. However, due to the complexity of the issue and extreme computational demands for numerical works, most studies have focused on experimental investigations.

Coberly (1937) investigated the bridging phenomenon and concluded that stable bridges would form if the screen opening is less than D10 (i.e., sieve opening size that lets 90% of grains to pass through). He found 2D10 as the upper limit for the opening size beyond which stable bridging won’t happen. Rogers (1971) and Suman et al. (1985) also suggested D10 as the optimum opening size for both WWS and SL completions. Gillespie et al. (2000) proposed 2D50 and 2.5D50 as the maximum opening size for WWS and PSs, respectively. Weatherford guidelines (2010) suggest D25 for WWS and D5 or D10 for PSs. Fermaniuk (2013) proposed the following criteria based on the existing experimental investigations and field experience:

2.0D70 <Slot Width < 3.5D50 or 2D10

Above-mentioned criteria have been proposed based on the assumptions that (1) the opening geometry (size and profile) is constant during the operation, and (2) the shear and normal stresses/displacements at screen-formation interface do not have an effect on sanding. However, these assumptions are not always valid and plugging/corrosion (Romanova and Ma, 2013; Romanova et al., 2014), erosion (Procyk et al., 2015; Fermaniuk et al., 2015), and thermal stresses/deformations (Xie et al., 2007; Xie and Solvoll, 2009) could challenge them.

Thermal expansion/contraction of liners has been addressed in the literature. Seismic evidence has been reported and tied to the liner expansion during the SAGD operation (Maxwell et al., 2008). It has been shown that if these thermal expansions/contractions are restricted, significant tensional and compressional stresses are developed in the liner, which could cause plastic yield and buckling (Dall'Acqua et al., 2005; Kaiser, 2009; O'Rourke, 2010). Excessive deformations in the screen could severely affect the opening size and shape (Xie et al., 2007; Xie and Solvoll, 2009). Different tools, measures, and techniques (such as using different production techniques for WWS or installing slip joints and axial load control devices) have been developed to avoid excessive compressional and tensional stresses (Slack et al., 2000; Cavender et al., 2011; Van Vliet and Hughes, 2015) by facilitating the liner's expansion/contraction.

Normal stress develops at the interface of the oil sand formation and the screen as unconsolidated oil sands collapse and fill the initial gap between the sand face and the liner. This stress can affect the bridge of sand grains behind the slots. However, the amounts of normal stresses are small in early stages of the SAGD operation. Hence, current criteria are still relevant for the early life of the well. Of course, normal/shear stresses at the liner-sand interface are also critical parameters when it comes to assessing the mechanical integrity of the liner (Slack et al., 2000; Dall'Acqua et al., 2005; O'Rourke, 2010; Van Vliet and Hughes, 2015). The authors could not find published works on the evolution of liner-oil sand interface in terms of porosity, permeability, shear and normal stresses, and deformation despite its importance in the liner and reservoir performance.

The current industrial approach for SCD design in Western Canada varies for different producers and manufacturers. Nevertheless, common traits for SL design can be outlined as follows:

1. Core or bailed samples from a few points from the oil sands are collected to represent the variation of the PSD.
2. Safe slot width window is specified for all PSDs, based on the existing sand control criteria.
3. The final slot width is chosen based on the best fit for all PSDs, previous knowledge for similar wells/projects and economic/manufacturing considerations.
4. The slot profile is selected based on the fines (grain size <44µm) content of the sample. Seamed slots are usually suggested for large fines contents (>5%).
5. The number of slots is calculated based on the expected flow rate to ensure a flow rate of about 40 ml/hr for each slot. This flow rate is determined based on the long-term experience for slotted liner applications in SAGD projects.
6. To compensate for the possible plugging of the slots, the number of slots is multiplied by a plugging factor.
7. After the final selection, a coupon of the selected screen is tested to assess its sand control and flow performance according to the testing protocol developed by Bennion et al. (2008).

The common industrial practice of fitting one opening size to the entire length of the horizontal well has been criticized (Mahmoudi et al., 2016b). This is because the PSD may highly vary along the well. At the same time, it is not practical to change the slot size in short intervals. A balance should, therefore, be struck between providing adequate variations in the liner design within the practical realm.

EVALUATION TESTS OF SCDs

Evaluation tests are usually performed to verify the screen design and to evaluate, optimize, and compare the SCDs (Ballard et al., 1999; Ballard and Beare, 2003, 2006, 2012; Bennion et al., 2008; Weatherford International, 2010; Romanova et al., 2014). Some of these tests have been widely accepted as the reference test for screen evaluation (Bennion et al., 2008). This review only focuses on the evaluation tests developed to assess the sand control and flow capacity. There are also evaluation tests to assess the mechanical integrity of screens (Lee et al., 2008; Hamilton et al., 2009), but are beyond the scope of this paper.

Screen evaluation tests could be classified into three groups: (1) slurry Sand Retention Tests (SRTs), (2) pre-packed SRTs and (3) full-scale liner tests.

Markestad et al. (1996) developed a laboratory model by using sand pack samples and establishing an upward flow towards the screen located 3-4 cm above the sand surface. They included a gap between the sand pack and the liner coupon to simulate the initial gap between the sand face and the liner. They found the upward flow would fluidize the sand but hardly lifts the larger grains unless for high rates which are not within typical flow rates in SAGD wells.

Later, Ballard et al. (1999) used a different set-up to perform SRTs using slurry flow. They placed a coupon of the screen in a flow loop and pumped a mixture of reservoir sand with low concentration through the screen.

In slurry SRTs, the differential pressure across the coupon is measured during the test. As the sand grains and fines accumulate over the screen, the pressure drop drastically increases due to the formation of a sand bed over the screen. A limit is assigned for the pressure drop (e.g. 100 psi) to gauge the flow capacity of the screen (Chanpura et al., 2011).

The assumption in slurry SRT tests is that the gap that initially exists between the formation sand and the screen liner remains open throughout the wellbore life. It is believed, however, the gap does not remain open and collapses due to the unconsolidated nature of the oil sands to form a high porosity/permeability zone around the screen (Boone et al., 1997; Kaiser et al., 2000; Carlson, 2003). The collapse of the formation around the wellbore prevents the annular flow as the initial gap is closed. Therefore, pre-packed SRTs are more representative of the actual well conditions and are widely used for screen design evaluation.

In most pre-packed SRTs, a certain amount of sand is packed above the screen coupon. Some axial stress is also applied to avoid channeling in the sand pack (Ballard and Beare, 2006). During the pre-packed SRT, the main measurements are the produced solids through the screen and the pressure drop across the screen and the sand pack as a function of time.

Screen evaluation tests have mainly focused on sand production and flow performance. However, they have been also used to address the plugging tendency and longevity of the screens. Due to the limited duration of these tests, they are limited in capturing complex phenomena such as liner corrosion, scaling, screen plugging, and pore plugging. The flow rates in SRT tests are usually ramped up during the test to simulate the higher velocities at the open slots as some slots are expected to plug during the well life cycle. Testing protocol developed by Bennion et al. (2008) suggests the use of fluid flow rates as large as ten times the expected field rate. Results of such tests need to be normalized for OFA (O'Hara, 2015) as unrealistically high flow rates may lead to biased results in favor of the screens with higher OFA.

Results of pre-packed SRTs indicate that the produced sand and flow capacity are dependent not only on the slot aperture size but also the flow velocity. Flow velocity, in turn, depends on the slot width and spacing. Conventional tests on single slot coupons, such as those performed by Bennion et al. (2008) cannot properly capture the effect of slot spacing and interaction between the slots on the produced sand and flow capacity. To address this deficiency, Mahmoudi et al. (2016a) developed a pre-packed SRT that incorporates multi-slot coupons.

Some researchers (Chenault, 1938; Asadi and Penny, 2000; Qi, 2004; Jin et al., 2012) developed full-scale testing apparatus to study the effect of converging flow around petroleum wells on the completion performance. However, full-scale tests are yet to be deployed for screen evaluation testing in SAGD due to cost and complex nature of the testing. Still, full-scale evaluation tests can be of high value to assess the flow capacity of SCDs in SAGD applications.

There is a growing interest in screen evaluation testing at larger scales than is currently established in single-slot or small-diameter coupons (Mahmoudi et al., 2015). Large scale tests need a large quantity of sand. However, oil sands samples from target depths are generally limited. This necessitates the replication of oil sands with commercial sands and fines.

Mahmoudi et al. (2015) performed a comprehensive characterization study on oil sands samples from two wells in McMurray Formation and a large number of commercial sand and fines samples. They concluded that it is feasible to use commercial sands/fines to replicate oil sands for the purposes of sand control testing.

In addition to using the representative sand grains, it is also important to use representative fluid flow for evaluation tests. Mahmoudi et al. (2016a) showed the prominent effect of the pH and salinity of the injected fluid in pre-packed SRT tests on fines movement, formation damage and screen flow capacity. They also showed that test results are highly dependent on fluid velocity.

SCD FAILURE CASES

The design and types of SCDs have evolved in relation to the learnings that have taken place from the success and failure cases since the advent of SAGD in the 1970's. Only a limited number of screen failures have been reported in detail in the literature. Those reported failures could be categorized in relation to the failure mechanism, screen type, and failure source (e.g., incorrect design, operational conditions, and thermo-chemical interactions in the screen vicinity).

This section reviews the reported failure cases and if/how they could be avoided.

FAILURE DUE TO THE OPERATION

Some SCD failures are related to the general operation and they have not been the result of the problematic design. Sanding and erosion due to the steam breakthrough is a prominent example. Butler (1998) considered the steam-driven screen erosion among the main pitfalls and problems of the SAGD technology.

Steam breakthrough is usually avoided to improve energy efficiency by reducing Steam Oil Ratio (SOR) and to maintain the health of the well completion. Steam breakthrough can cause extreme slot erosion by allowing the flow of sands and fines at extremely high velocities. Typically, steam-trap control acts as a tool to control or prevent the steam breakthrough (Doan et al., 1999; Das, 2007).

The high-velocity fluid flow at the vicinity of the screen can be also the result of aggressive production (Williamson et al., 2016). Williamson et al. (2016) studied the failure of a horizontal well in Lower Grand Rapid Formation. They reported the oil sands in that particular project as clean with less than 5% of fines. The sand grains were reported as sub-round. The D10 and D50 were about 0.009" and 0.005"-0.006", respectively, around the injector and producer wells. Based on the sand control evaluation tests and economic considerations 0.020" to 0.012" RT SL was chosen for the wells. A steady increase of production to 400 bopd was observed for 8 months. This ramp was stunted by facility turnaround. When the facility was brought back to production, a 1 MPa surge in differential pressure between the injector and producer was observed. It was presumed that aggressive ramp up of the submersible pump caused extreme flow velocities, which accelerated the fines migration and caused pore plugging and pressure drops in the liner vicinity.

The failure experience outlined by Williamson et al. (2016) emphasizes the role of careful well operation to avoid high fluid flow velocities at the wellbore vicinity as fines movement is extremely sensitive to the flow velocity. This is consistent with the experimental observations of Mahmoudi et al. (2016a). They observed that fines movement is highly dependent on the flow velocities. They also found that large flow velocities can reduce the permeability near the liner. Flow control devices could be used to control production rates.

FAILURE DUE TO SAND CONTROL DESIGN

There are cases which seem to have a direct relation to the SCD design. One of the most discussed screen failures in the literature is the case reported by Slack et al. (2000) and Kaiser et al. (2000). The failure was related to a SAGD production well in South Bolney field. The well was first completed by KC SL with 0.060" slot width to encourage the inflow leading to unacceptable sanding during the production. Due to the massive sanding, the slot size was gradually reduced in subsequent drilling programs to 0.025", 0.018", and finally 0.012". Every reduction in slot width reduced the sanding but the problem still existed. Finally, WWS with 0.005" opening size was installed within the slotted liner for some wells. Above-mentioned issues resulted in a complete review of the completion program. SL with slot width of 0.006", based on 1.5D50, was chosen and installed for one of the production wells. No sanding was reported for the studied well (Kaiser et al., 2002).

FAILURE DUE TO THERMO-CHEMICAL REACTIONS IN THE VICINITY OF THE SCREEN

One may improve the design and manufacturing of the screens by considering the PSD and fines content and improving the slot/opening quality/geometry. However, there are still mechanisms such as scale deposition (Brand, 2010; Lalchan et al. 2011), silica precipitation (Fermaniuk et al., 2015), corrosion (Fermaniuk et al., 2015), and thermal formation damage (Romanova et al., 2015). These phenomena are influenced by thermo-chemical reactions/interactions between the injected steam and the formation fluids and minerals, and mineralogical diagenetic alterations (Bennion et al., 1992; Romanova et al., 2015). These phenomena are hard to avoid and may require frequent stimulation services (Brand, 2010; Lalchan et al., 2011).

Geological conditions determine the mineral/chemical composition of the formation. However, operators may still consider optimizing such parameters as alkalinity of the injected steam, companion gasses, and additives to the injected steam to minimize near wellbore formation damage (Mahmoudi et al., 2016a). They can also consider improved screens (such as coated screens), which provide better surface quality to reduce corrosion and scaling (Fermaniuk et al., 2015).

MISCELLANEOUS CASES

There are some cases that cannot be simply considered in a single category as different phenomena may combine to result in screen failure. The failure case discussed by Romanova and Ma (2013) is a good example.

Romanova and Ma (2013) investigated the SLs recovered from the McMurray Formation in the Long Lake area. They reported a large number of plugged slots with predominantly corrosion products and clays. Slots were originally 0.018" to 0.0135" RT. Measurements on recovered liners showed that the slot aperture at the top and bottom entry had decreased, on average, to 0.015" and 0.012", respectively. The change in slot aperture can be attributed to corrosion and plugging. However, Romanova and Ma (2013) considered the possibility that the liners had originally been manufactured with slots slightly smaller than their nominal size. Thermal and installation related deformation and stresses could also have affected the slot size, as Romanova and Ma (2013) also detected deformed slots with sizes larger than their nominal size. Another contributing factor can be the screen corrosion at the surface prior to installation.

Different sources for this failure case are possible: inappropriate design of opening size, neglecting thermal stresses in the liner design, problematic manufacturing and thermo-chemical interactions which cause corrosion and trigger the plugging. However, Romanova and Ma (2013) concluded that the main source of failure was plugging for their studied liners.

Plugging has been mentioned as one of the main sources of failure for screens elsewhere (Bennion et al., 2007 and 2008). Corrosion products have widely been mentioned to contribute to plugging (e.g., Romanova and Ma, 2013; Romanova et al., 2014). Further, screen plugging increases the flow velocity behind the open slots, resulting in further fines movement, lower retained permeability (Mahmoudi et al., 2016a), and higher liner erosion potentials (Procyk et al., 2015; Fermaniuk et al., 2015). Hence, pore and slot plugging, corrosion, and erosion are interrelated.

Bennion et al (2007) listed the factors with influence on plugging as follows:

- Particle Size Distribution of the formation, especially the concentration and size distribution of fines (less than 44 μm)
- Formation wettability,
- Slot manufacturing quality (surface roughness, and quality control),
- Rate and type of the fluid flow (single phase oil, oil and brine, oil and brine and gas/steam),
- Annular failure of sand faces onto the liner,
- Residual filter cake/drilling mud.

Improper SCD design, for instance, incorrect opening size and slot profile, can exacerbate the plugging.

DISCUSSION AND CONCLUSION

This paper reviews different aspects of SCD design based on published reports/papers and discussions with SCD designers/manufacturers.

Sand Control Device design is a complicated procedure with different considerations: mechanical integrity, sand control, flow capacity, corrosion, erosion, fluid-mineral interactions, reservoir management, and operational conditions. This review focuses mainly on the sand control and flow capacity aspects. Other considerations are also addressed if they affect sand control and flow capacity.

This paper also provides a review of reported SCD failures and categorizes them into three groups: (1) avoidable by improving the SCD design, (2) avoidable by improved operation, and (3) failures which are related to thermo-chemical interactions between the minerals and fluids in the vicinity of screens and are not easy to avoid by merely improved design or better operation.

SAND CONTROL

The most important design parameter in sand control is the slot opening aperture. Certain points on the PSD curve (D values such as D50) are used in the existing design criteria to assign the aperture size. These D values may not adequately represent the entire PSD curve.

In practice, aperture sizes are first determined for different PSDs along the horizontal well using the design criteria. Next, the best aperture size is chosen to provide best sand control for the entire well length. This procedure is highly subjective and is based on best practices for similar projects and formations. Fitting one opening size to the full length of the well has been criticized. However, the PSD can highly vary along the well length, making it impractical to change the liner specification over short intervals.

Existing design criteria do not consider the possible deformations in the slot geometry and the role of normal and shear stresses in the vicinity of the screen. Unintended screen deformations can highly affect the screen opening size, hence, its sand control and flow capacity. Moreover, normal and shear stresses/deformations can influence the stability of the sand bridge behind the slots. These amounts of stresses/deformations are dependent upon the evolution of the annular gap at the formation-screen interface.

Another issue which is usually ignored in the design criteria is the grain shapes. Research is required to determine the variation of grain shapes in oil sands formations across Western Canada, to see if it is worthwhile to include the grain shape parameters in the design criteria.

Erosion, either due to the high-velocity steam or high-velocity fluid on some slots as a result of extreme plugging in other slots, can also affect the sand control. Erosion can increase the opening size and result in massive sanding. This can lead to total liner failure in extreme cases.

Sand control capacity of screens is evaluated by certain tests. These tests focus mainly on the aperture size. Using reasonable levels of fluid flow rate is important because sanding is affected by the flow velocity. Moreover, normal/shear stress/deformations at the sand-screen interface are usually ignored in these tests, whereas these stresses/deformations may affect the bridging.

FLOW CAPACITY

The flow capacity of SCDs is usually related to the OFA. However, there are discussions on the amount of OFA which is actually required. Proponents of low-OFA screens (i.e., SLs) argue that the additional cost for the extra OFA is unnecessary if the original OFA is kept open by correct design and high-quality manufacturing. On the other hand, high-OFA screens (i.e., WWS and PS) are justified by the fact that plugging of screen openings is a common phenomenon in SAGD and extra OFA is necessary to maintain the required production in the long term.

Plugging of screen opening has been considered as one of the main sources of screen failure. Plugging can be the result of (1) inappropriate opening geometry which does not facilitate the fines discharge that enters the opening, (2) corrosion which acts as the preliminary stage for plugging, and (3) combination of the plugging and scaling. Proper SCD design, high manufacturing quality, and use of improved materials (e.g., coated screens) can help to avoid the screen plugging.

Thermo-chemical interactions between the formation minerals, formation fluids, condensed steam, exsolution gas, and mineral transformations can affect the fines movement and cause pore plugging in the screen vicinity. Moreover, these interactions can lead to the deposition of organic (asphaltene) and inorganic (carbonate and silica) scale on screens and in the near wellbore pore spaces.

Reported failure cases indicate that SAGD wells are highly sensitive to aggressive production. High-velocity fluid flow at the vicinity of the screen can cause fines movement, which increases the potential for pore plugging. Pressure drop due to flow convergence also increases as a result of high-velocity fluid flow. Flow control devices may be employed to help control production rates.

Designed screens are usually evaluated with certain tests to assess their fluid capacity. These tests usually use the pressure drop across the sand pack/slurry and screen as the main parameter to evaluate the flow capacity of the screen coupons. Single slot coupons are commonly used to evaluate SLs. These tests ignore the interaction between the slot density and the slot width. Evaluation tests with multi-slot coupons are more relevant for this purpose.

It is also important to consider more realistic conditions for the evaluation experiments in terms of fluid flow rate and fluid composition. Using rates, higher than the common rates in the field, can produce biased results in favor of the screens with higher OFA.

Stresses, porosity, and permeability at sand face-screen interface evolve during the SAGD operation as the initial gap between the sand face and screen closes. Flow capacity of the screen and the near-wellbore zone can be affected by this evolution. However, these phenomena are usually ignored in the evaluation tests.

Large-scale evaluation tests are gaining more interest as they provide more realistic conditions. These tests necessitate oil sand replication as actual oil sands samples are limited and costly.

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NOMENCLATURE

D10	Sieve opening size that lets 90% of grains to pass through
D50	Median size on the PSD curve
D70	Sieve opening size that lets 30% of grains to pass through
DIA	Dynamic Image Analysis
GS	Gang Slot
HS	Horizontal Slot
KC	Keystone Cut
LPSA	Laser Diffraction Particle Size Analysis

LS	Line Slot
OFA	Open to Flow Area
OPEX	Ongoing Operating Expenses
PPS	Precise Punched Screen
PS	Premium Screen
PSD	Particle Size Distribution
RT	Rolled-Top
SA	Sieve Analysis
SAGD	Steam Assisted Gravity Drainage
SC	Straight Cut
SCD	Sand Control Device
SL	Slotted Liner
SRT	Sand Retention Test
SS	Staggered Slot
WWS	Wire-Wrapped Screen

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FIGURES

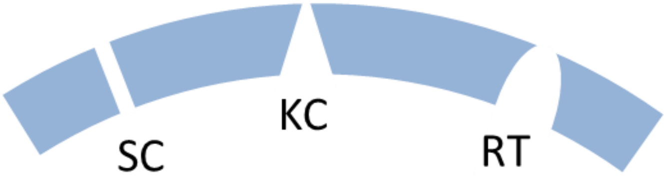

Fig. 1. Common slot profiles for slotted liners: Straight Cut (SC), Keystone Cut (KC), and Rolled-Top (RT) or seamed

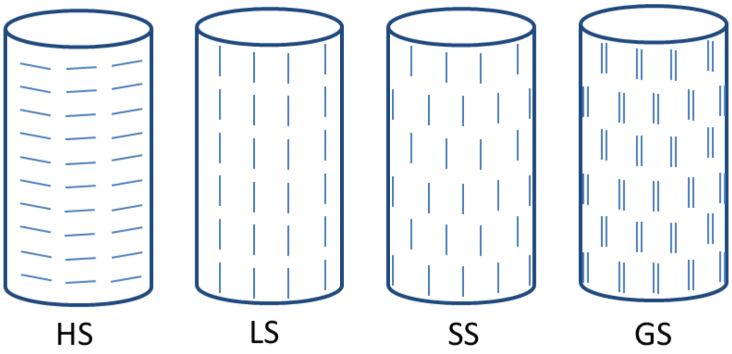

Fig. 2. Common slot patterns for slotted liners: Horizontal Slot (HS), Line Slot (LS), Staggered Slot (SS), and Gang Slot (GS)

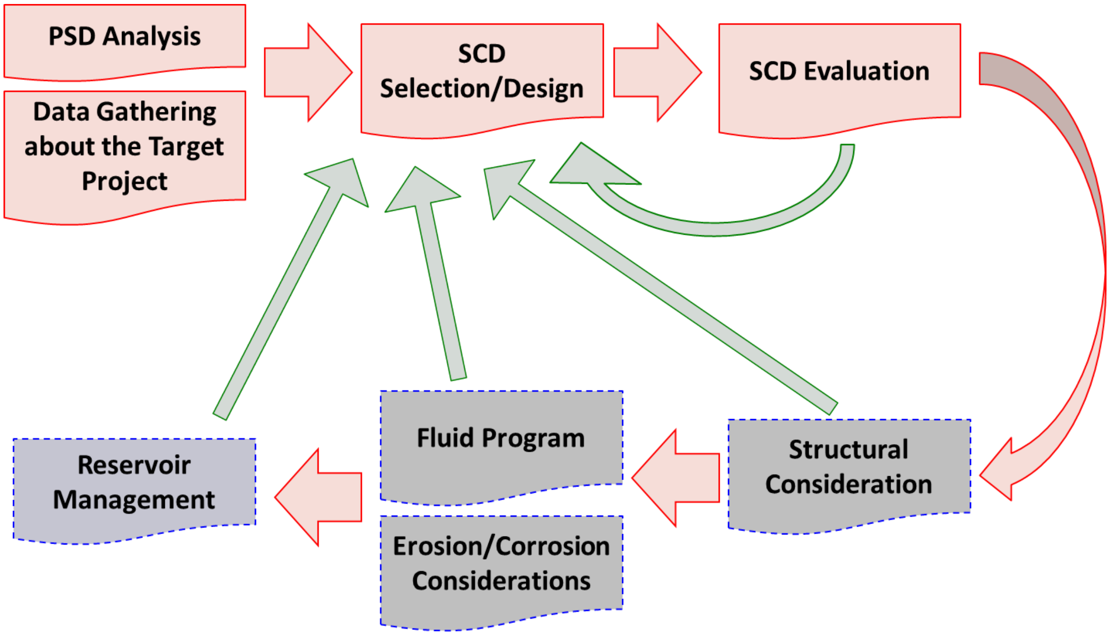

Fig. 3. General procedure of completion design