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Stand-Alone-Screen Candidate Selection Methodology

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Stand-Alone-Screen Candidate Selection Methodology

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Engineering

The University of Texas at Austin

December, 2011

Acknowledgements

I am grateful to the operator for supporting this project at the University of Texas at Austin, and I appreciate Andrew Hudson, Andrew Tallin, Kevin Bowlin and Lou Daigle for their assistance.

I am very thankful to my supervisors Dr. Kenneth Gray and Ms. Masa Prodanovic, for their support and guidance in my thesis.

Finally, I would like to thank my family and friends for their continued support during my studies at the University of Texas at Austin.

Abstract

Stand-Alone-Screen Candidate Selection Methodology

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The University of Texas at Austin, 2011

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An operator has some deepwater horizontal oil producing wells with stand-alone-screens (SAS) or unintentional SAS (incomplete open hole gravel packs). The objective of this project is to review sand control and production in these wells; to assess selection criteria for SAS; review factors that influence SAS performance such as bean up, fluids and contingency planning; and to provide recommendations with respect to SAS criteria.

This project could save $ 6 - 8 million per well for the deepwater operator. SAS offers reduced cost, skin, complexity and logistics, which are necessary to make some well projects economical. The risk in deepwater subsea operations is an earlier workover costing about $39.2 million. In the past, this has made some operators recommend SAS for land and shallow offshore only. However, there are deepwater wells where open hole gravel packs are not preferred such as low cost wells, wells with unstable formations that bridge off the hole quickly, wells with narrow pore pressure-fracture pressure windows,

high pressure/high temperature wells with fluid compatibility issues, tortuous wells seeking multiple targets, extended reach wells, etc. More recently, some operators are now using SAS for carefully selected non-traditional SAS candidates based on tests and other important factors.

At the end of the study of the operator's wells, it was concluded that six out of seven wells with SAS were successful because they had zero to minimal sand production and good oil flow as expected. This is an 85% success rate. The operator had more conservative selection criteria for SAS than the wells parameters. Shales were isolated with blank pipes in the wells. Well surveillance will be continued to see how the wells perform over the years. The operator was advised to adjust their selection criteria by a moderate percentage, as long as the SAS to be used is physically tested with a laboratory model to validate use of the SAS in such wells.

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CHAPTER 1

INTRODUCTION

Sand production happens in oil and gas wells when the formation has low rock strength and has local and regional loads that cause the formation to crumble and release sand particles that flow with reservoir fluids from down hole to the surface. Unconsolidated rock has unconfined compressive strength around 80 psi or less. Regional stresses (Figure 1.1) imposed on the perforation and wellbore such as horizontal and vertical stresses may be put into analytical, numerical or empirical models in order to predict sand production. Local loads are imposed on the perforation or wellbore due to the hole, flow, reduced pore pressure, drawdown or water breakthrough. Shear failure caused by drawdown can break sand grain bonds. Tensile failure caused by high petroleum production rates can dilate a mass of sand grains and cause them to crumble. Fluid viscous drag forces pull the failed grains from the perforations into the wellbore. In the case of an open hole completion, high stresses at the hole could make a formation fail under compression.

Sand control is important because sand erodes tubulars and surface equipment; leads to loss of integrity, reduced hydrocarbon production and can cause fatalities in the field. Solids control is achieved by using frac-packs, gravel packs, screens, selective perforation or controlled flow. Sand production and control is a wide and developing field of work that goes beyond the scope of this thesis. This paper is focused on Stand Alone Screen candidate selection methodology.

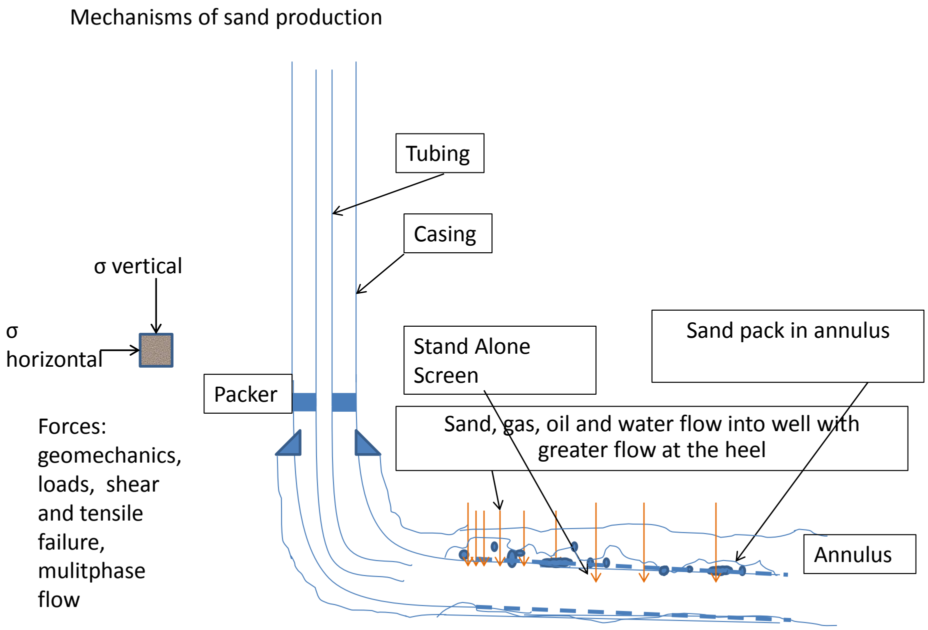


Figure 1.1 Mechanisms of Sand Production

Sand control screens

Stand Alone Screens are usually made of AISI 304L, AISI 316L stainless steel or Alloy 825 for the jacket, with a base pipe made of carbon steel or 13 Cr steel. These materials are good for CO_2 service up to 120^oC and are also resistant to other types of corrosion e.g., oxidation, reduction, etc. For more details on the metals and alloys used for SAS, refer to textbooks or sand management guides from industry.

Stand Alone Screens (Figure 1.2) are used for well completions because of their lower cost and reduced complexity, skin and logistics. They are better for some types of wells such as high-angle and tortuous wells. Screens are run into cased or open hole, with or without gravel packing, and also into a hole with a pre-drilled liner. The four main types of screens are

- Slotted liners
- Wire-wrapped screens (WWS)
- Pre-packed screens (PPS)
- Premium screens (mesh or woven screens)

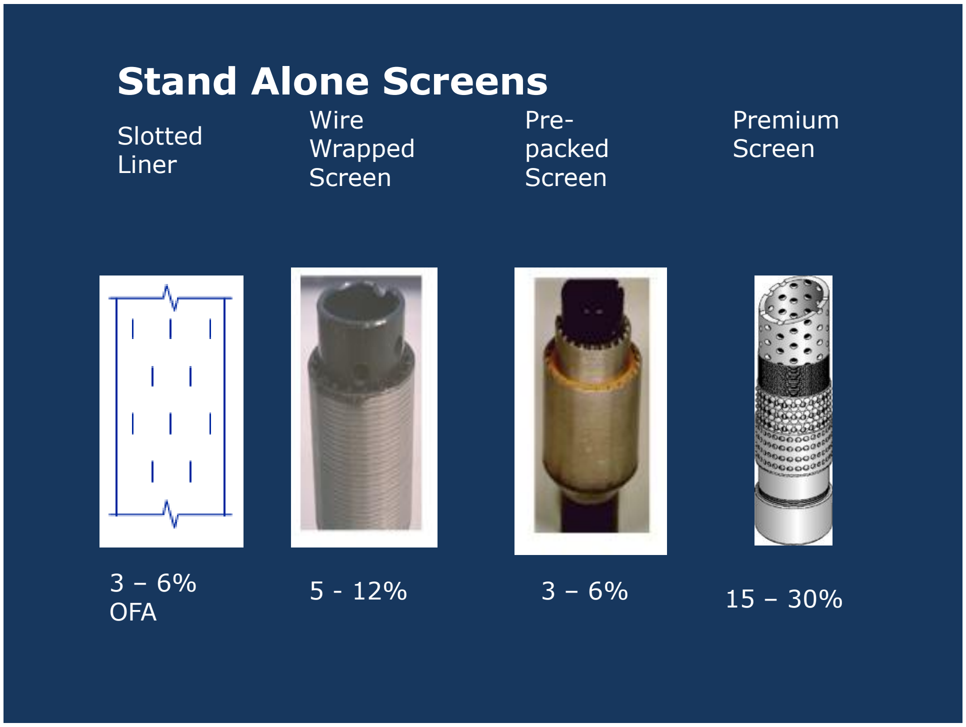
Slotted liners: are tubing sections with axial slots cut in the pipe wall.

Advantages of slotted liners: Lowest cost type of screen.

Disadvantages of slotted liners:

- Flow area through the liner is limited to 3 – 6%.
- Tensile strength is satisfactory, compressive strength is affected because rigidity is low. This means great care must be used, if they are to be pushed to the bottom of the well. Compressive and torque rating are improved by offsetting slots.

Figure 1.2 Stand Alone Screens



Wire-wrapped screens: Frequently used in gravel-pack and stand-alone completions. They comprise of a base pipe with holes, longitudinal rods and a single wedge or keystone-shaped wire wrapped and spot welded to the rods (Figure 1.3). The wire wrap could be slip on wrap or direct wrap. Direct wrap on pipe screens have the longitudinal rods mounted on the base pipe, then the wire jacket is wrapped and welded directly over this assembly, providing a very tight shrink fit. This process eliminates the requirement of welding to the base pipe, and creates a base pipe and jacket arrangement that behaves like a single part. The direct wrap on pipe screens have been said to be better at withstanding high mechanical forces which you might encounter in a long horizontal well.

Wire-wrapped screens are only suitable as a stand – alone completion if they are used for well-sorted, clean sands, because the slot spacing can be accurately sized. Spacing between wires is 0.001 to 0.002 inches. Inflow area depends on wire thickness, slot width and percentage of screen joint that comprises slots. Thinner wires provide more inflow area.

Advantages of wire-wrapped screens:

- Sand is stopped by the wedge shape of the wire – coarser particles bridge off while fine materials might pass through the screen. Wire-wrapped screens have self cleaning properties.
- Even if inflow surface area is only 5%, it is still more than the flow area of a cased and perforated well. Inflow area is between 5 and 12%.

For gravel pack completions, wire wrapped screens stop the gravel and fine material will be stopped by the gravel or produced through the screen.

Disadvantages of wire-wrapped screens:

- Acid jobs and other chemical treatments can be damaging to the wire and open up slots.
- Base pipe failure rates are low, but collapse has been reported when the screen has plugged up.
- Wire-wrapped screens are more prone to erosion than other screens.
- Prone to damage during deployment.

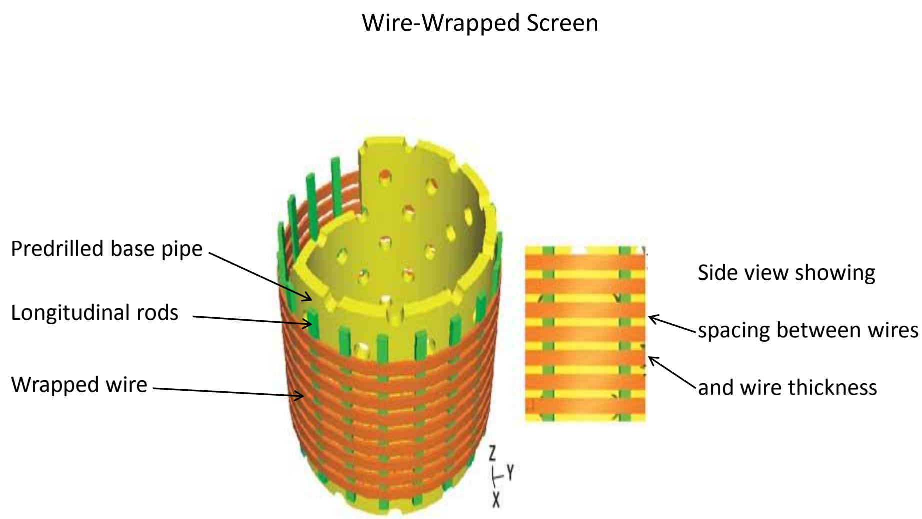


Figure 1.3 Wire-wrapped Screen (modified from Jueren et al, 2008)

Pre-packed screens: are similar in construction to wire-wrapped screens but have two screens with resin-coated gravel between them. Screen slots are sized to prevent the escape of gravel packed between the screens. The gravel is consolidated to prevent a void from developing.

Advantages of pre-packed screens:

- Provide minimal pressure drops due to high porosity (over 30%) and high permeability.
- Pre-packed screen can serve as a pack, just in case the hole is incompletely packed during a gravel pack job.

Disadvantages of pre-packed screens:

- Prone to plugging. To provide jetting resistance, they can have an outer shroud.
- Handling during installation can cause brittle thermo-set plastics in them to crack.
- Inflow area of about 3-6%.
- Reduced internal diameter.

Premium screens: Screens constructed with a woven mesh and an outer shroud for protection. The layers are: predrilled base pipe, drainage layer, sand retention woven mesh layer and an outer shroud (Figure 1.4). There may be multiple drainage layers. Mesh media can be sintered or diffusion bonded for additional strength.

Advantages of premium screens:

- Inflow area around 15-30%
- Porosity of mesh can exceed 60%
- Preferred for sand control in compacting reservoirs or harsh installation environments like long, horizontal, open hole wells.
- They are generally preferred to other screens for SAS.

Disadvantages of premium screens:

- They cost more than other SAS.
- Shroud stability and strength have to be adequate for the well and formation conditions.

Sketch of a Premium Screen

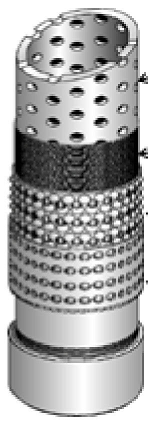


Figure 1.4 Sketch of a Premium Screen

Statement of the Problem

An operator has some horizontal oil producing deep water wells with stand-alone-screens (SAS) or unintentional SAS (incomplete open hole gravel packs). The **objective of this project** is to

- Review sand control and production in some of these wells
- Assess selection criteria for SAS
- Review factors that influence SAS performance such as bean up, fluids and contingency planning
- Provide recommendations with respect to SAS criteria

Value Added to the Company

This project could save $ 6 - 8 million[1] per well for the company if more applications for successful SAS use can be identified. If you are completing a large number of wells, this could grow into even more cost reduction. SAS offers reduced cost, skin, complexity and logistics, which are necessary to make some well projects economical.

Risks: Earlier workover costing about $39.2 million[1] . Workovers take place during the life of a well for recompletion and other issues. If an SAS completion fails early in the life of a well, then the cost of recompletion will be brought forward. The biggest contribution to this cost is the rig cost. The way to reduce the probability of an early failure is to be careful and use good methodology for SAS candidate selection.

Application of Stand Alone Screens (SAS):

<u>Screen selection and rigorous quality control</u> are important during installation. They are low cost, but have had some high profile failures. Wire wrapped and premium screens are preferred for SAS. Premium screens are generally preferred for SAS producers and WWS for injectors. Sand production problems have a greater impact on profit and safety if producers get impaired prematurely. Therefore premium screens,

[1] Based on data from Field A wells: A 14 & 19 have similar measured depth around 13000ft and water depth around 5000 ft, same reservoir. Cost of A 10 recompletion in 2011 figures.

which cost more but can be more robust, are used more frequently for producers – than WWS.

Expandable sand screens (ESS) have been used in order to prevent formation of a low permeability pack. ESS use in cased hole is less common. They have been used in open hole where the reservoir has many thin layers that are too spread out for a cost-effective frac-pack; when producing marginal reserves; when using limited funds and limited logistics; and where the hole diameter is small; completing a high-angle well; or completing a long reservoir interval. ESS systems are available with mechanical or passive expansion, offering conformance or non-conformance with the openhole.

The latest designs of ESS expand mechanically by washstring administered pressure. Other ESS may expand passively as they swell under reservoir conditions of temperature and pressure or expand when exposed to oil, water or both if a combination of elements is selected. Disadvantages of ESS include failure to expand and damage under overburden stress.

SAS may be used in extended reach wells, where it is not possible to do pumping and screen expansion.

Stand Alone Screen Failures

Stand Alone Screens have experienced a number of failures in the past (Bellarby, 2009) -- when they were used without proper understanding of the appropriate conditions for use in a well. Some of those failures have been caused by:

- Screen erosion exacerbated by screen plugging is a major cause of failure. Screen plugging happens when sand and/or fines get stuck in the screen. The sand could get resorted into a low permeability pack (see Figure 1.5), accumulate and get smeared onto the screen leading to smaller area for fluid flow, called hot spots.

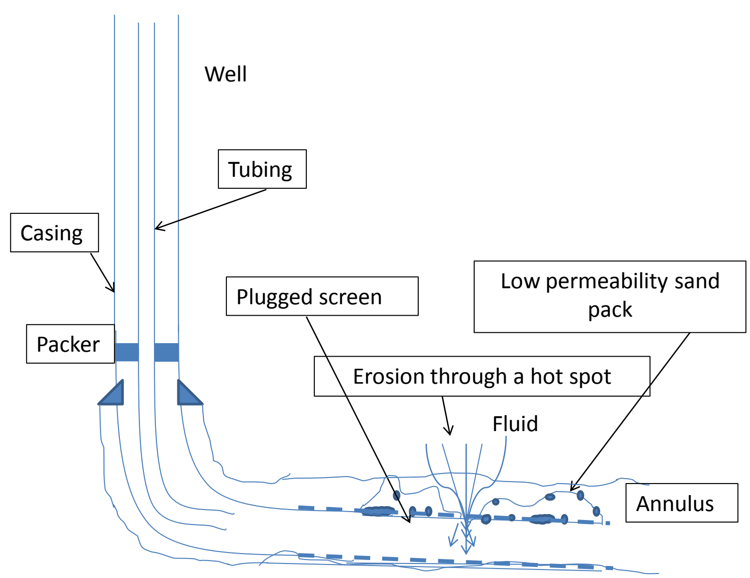


Figure 1.5 Plugged Screen

- In the Alba field (Chevron in North Sea) plugging was first caused by the pseudo oil based mud. The screens failed and sand was produced. Sized salt mud was used, but the screens still failed. Premium screens were used and they failed too. The formation had uniform particle size distribution, but reactive shales plugged the screens and created erosion prone hot spots. The open annulus and smearing of shales is avoidable with swellable elements in conjunction with SAS, expandable screens and gravel packs but could happen with stand-alone-screens. If blanks do not provide adequate isolation of shales, then reactive shales could get smeared onto the screens. Figure 1.6 shows reactive shales collapsing into a hole. Other important factors would be the content of the drilling and completions fluids; filtration of fluids during execution and solids sizing in the fluids.

- Heterogeneous reservoirs are more likely to fail than homogenous ones. Most reservoirs are heterogeneous, thus we could say increase in heterogeneity increases the likelihood of failure. Heterogeneous reservoirs are non-uniform in grain characteristics and lithology. In essence, the grain size distribution arriving at the screen is much wider and creates a lower permeability cake on the screen than is the case in homogeneous formations. Screen sizing also becomes more challenging when the formation has a wide grain size distribution. If a formation does not meet SAS selection criteria, then a gravel pack or frac-pack could be used for sand control instead.
- Formation collapse onto the screen in a low permeability pack if particle size distribution (PSD) is wide. In addition, the compaction of the formation created by this has caused mechanical failure of the screen.

- In gas wells, after water breakthrough, SAS have failed.
- High horizontal stresses cause grains to fragment and produce erosive fines.
- Low drawdown can cause incomplete cleanup and partial filter cake removal. This has led to screen failure.
- Premium and wire wrapped screens generally perform better than pre-packed screens as SAS.
- High pressure reservoirs that have formation damage from drilling fluid have experienced high differential pressure across the screen, which eventually cut the screen open (Colwart et al, 2007).
- Thick screens are also eroded.
- High rates especially in gas wells contribute to failure.
- High fluxes (flow rate per unit area) and high drawdown contribute to failure.
- High sand strength formations that later blast the screen can be worse than unconsolidated ones that collapse onto the screen quickly and form a natural pack.
- Some impaired wells have been caused by mechanical damage during installation or inadequate operations.

Selection Criteria

- The operator's criteria for use of SAS are generally conservative. Low UC, high N/G, low fines, high D_{50} are desirable formation characteristics for an SAS candidate. When UC (uniformity coefficient) is high, we have a non-uniform or poorly sorted sand. Uniformity Coefficient means D_{40}/D_{90}. D_{40} means 40% of cumulative weight percent are this size and above (See Figure 1.7). N/G stands for Net to Gross of adequate quality sand in the payzone. Geologic N/G is lower than sand N/G. Geologic N/G can be estimated from logs for the whole pay thickness. Sand N/G is also called petrophysical N/G; it is focused on the producing sand and is calculated from factors like Vsh (volume of shale) and porosity. Fines are grains that are 44 μm or smaller. Other factors like drawdown, shale reactivity, water depth and inclination angle through pay are also important. If angle through pay is 55 – 70 degrees a gravel pack job could become hard to accomplish (See Figure 1.8).

- Other oil and gas operators choose criteria like $D_{50} > 75\mu m$, narrow particle size distribution (PSD), uniform sand or well sorted i.e. $D_{40}/D_{90} < 3$, fines < 5%, few shale sections so that formation net to gross > 80%. Companies also desire a $D_{10}/D_{95} < 10$.

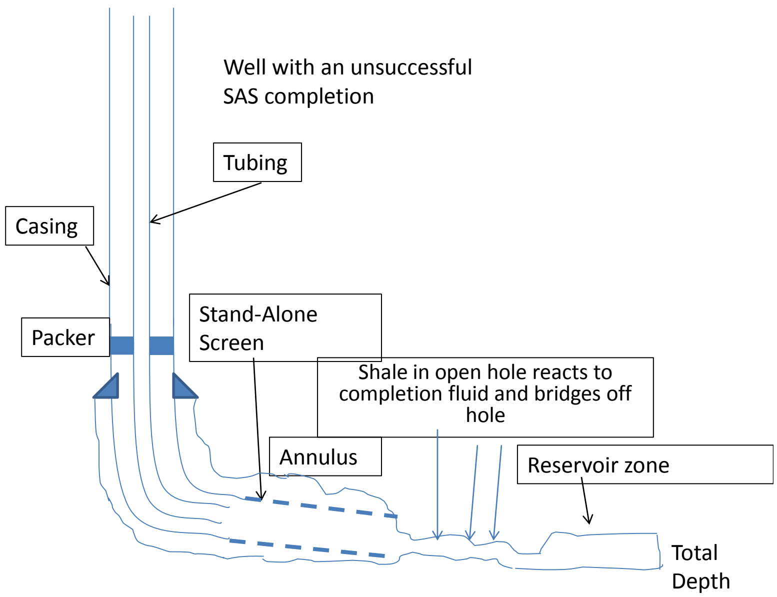


Figure 1.6 Reactive Shale Collapses into Hole

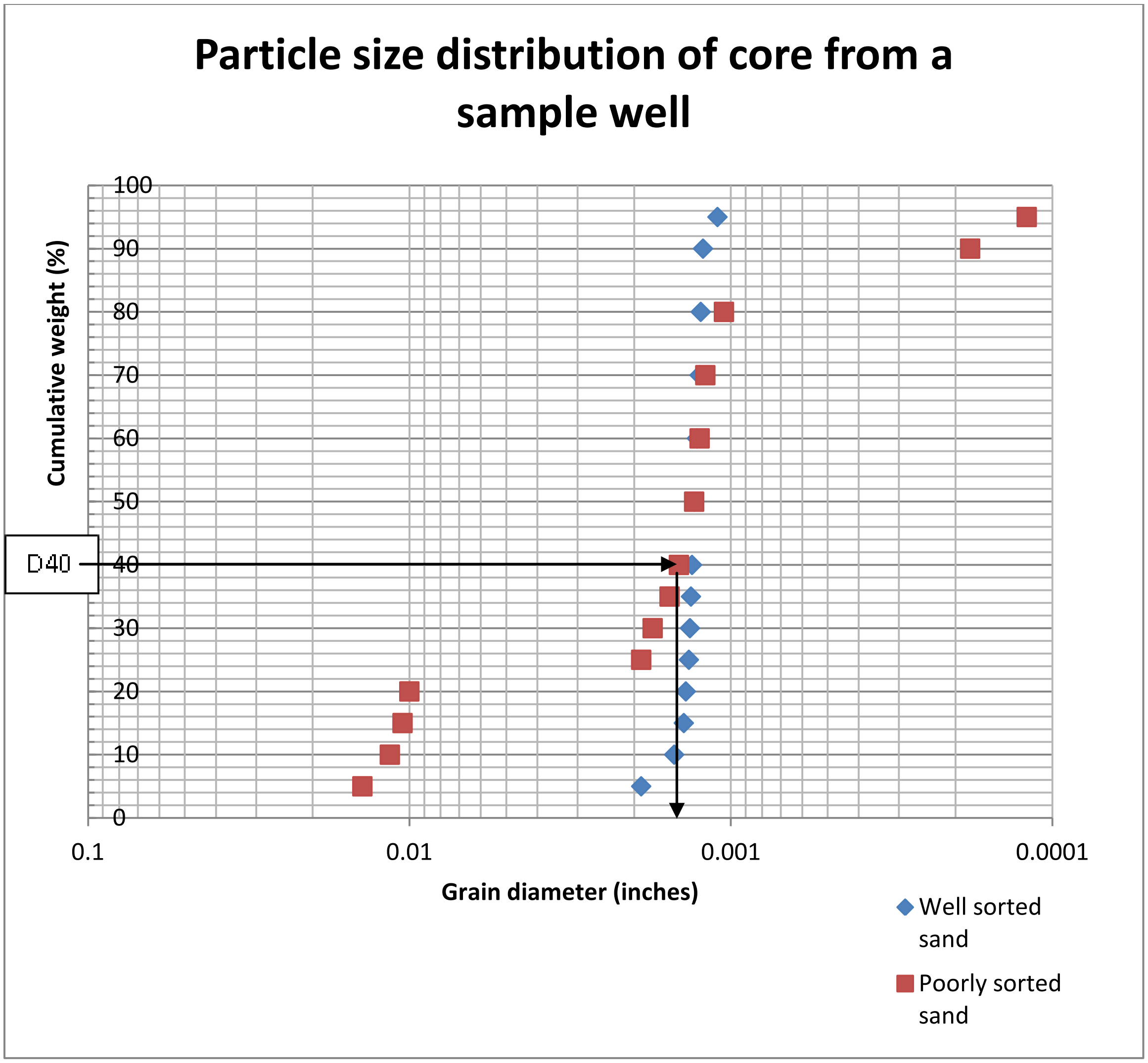


Figure 1.7 Particle Size Distribution of Core from a Sample Well.

- Some companies like Hydro Oil and Energy, Conoco Philips and Total expand their criteria to include non-traditional SAS candidates with screens chosen based on tests and careful selection of fluids and completion components.
- Completion fluid and quality control have been important during installation. Laboratory and well site tests were used to determine screen/ fluid combinations

and techniques. Oil based mud or synthetic based drill-in-fluid (DIF) are the most inhibitive DIFs. Viscosified brine or brines with amine may be used for less reactive shales.

- Operators have avoided mechanical damage by discretely controlling dogleg severity in the open hole; centralizing the screen; not applying too much weight when running the screen and avoid drilling out of gauge holes.
- Use of external packers for isolation of zones would have to be modeled and applied with caution to avoid a stiff bottom-hole assembly (BHA). A larger clearance between the wellbore and screen, means that the packers, when set, may withstand less differential pressure.
- Tools like inflow control devices (ICDs) have been used to reduce gas and water coning and annular transport of sand; which prevents formation of hot spots for erosion, manages drawdown and increases sand control reliability.

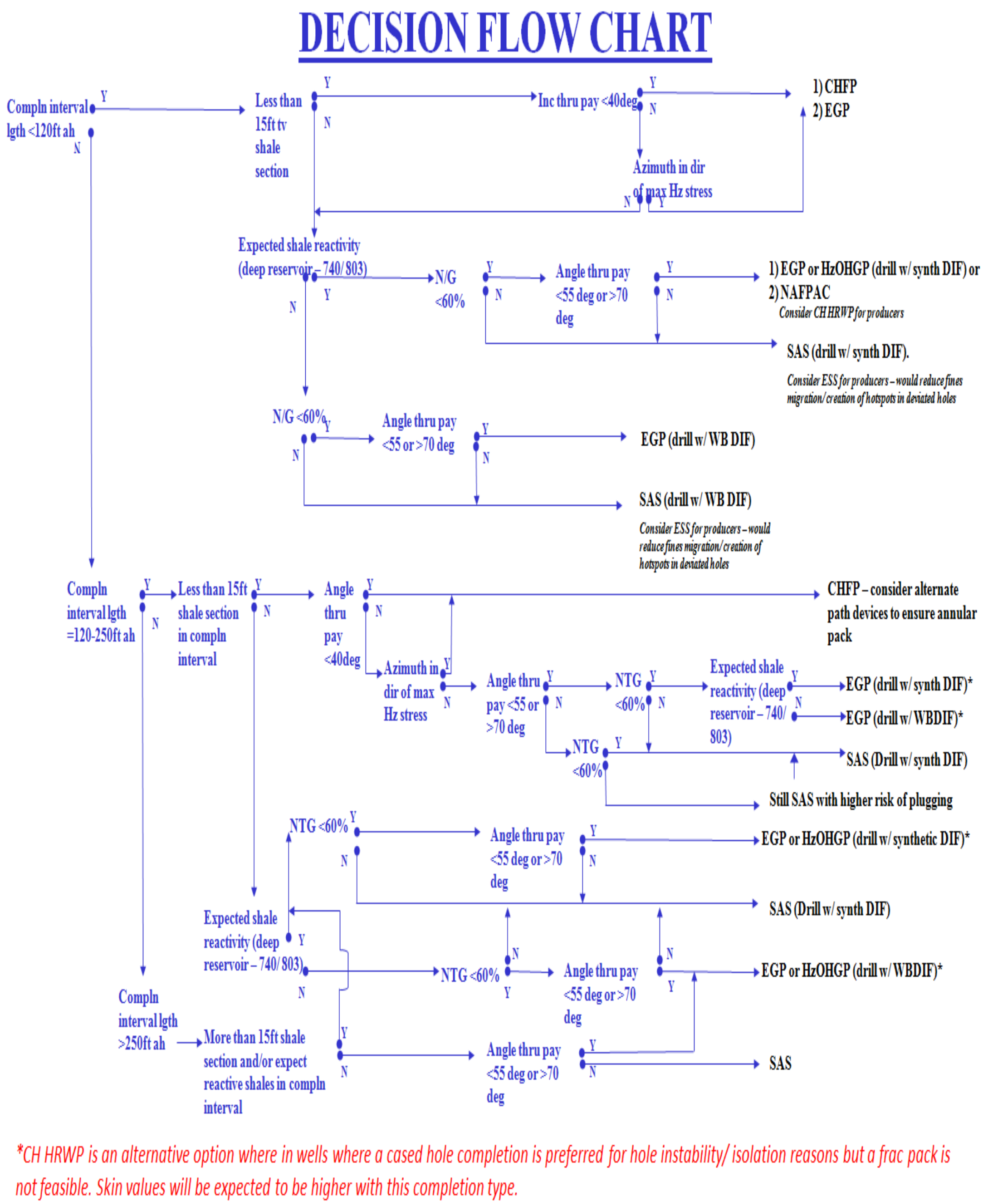


Figure 1.8 Decision Flow Chart for Field A’s Sand Control (Ekpo and Bogaert, 2008)

CHAPTER 2

LITERATURE REVIEW

Morita and Boyd, 1991 of Conoco Inc., have shown that core analysis can be done to determine the well pressure that will induce sand problems. They found that a gravel pack can be used for formation permeability less than 100 md. Their recommendations include: do not apply a gravel pack to waxy formations or those with fines migration to avoid a plugged gravel pack; formations with permeability above 500 md will experience too much skin if a gravel pack is applied. In this case, use core analysis to look for a strong zone that can be selectively perforated or reduce drawdown. Horizontal wells may be completed with Stand Alone Screens if rock and well conditions are suitable. An unconventional fracture pack may be used if possible.

Bennett et al, 2000 were involved in a Joint Industry Project (BP, ENI Agip, Conoco, Repsol-YPF, Chevron and Schlumberger) which proposed a design methodology for open hole horizontal completions, based on broad experience and global case studies. They considered factors like wellbore architecture, reservoir lithology, petrophysical properties, equipment reliability, intervention capabilities, fluids, clean up, screen type, operational implementation, torque and drag analysis and gravel placement simulations. Gravel packing was preferred for deepwater and subsea open hole horizontal completions because it avoided the high cost risk of workover if an SAS failed. However SAS or ESS were noted as possibly being applicable for challenging wells like high pressure and temperature wells where there would be issues with fluids and compatibility. Selection criteria for SAS completions included D10/D95 < 10, UC < 5, fines < 5%, high sand N/G, no compaction drive, no multiple shale sections, no high rate gas, small annular area outside the screen, low flux, low cost wells. (See the appendix of Bennett et al, 2000) If shale sections are few and blocky, it was proposed that they should be isolated with inflatable packers. Finally, the JIP worked towards establishing a database for horizontal sand control completions.

Underdown and Sanclemente of ChevronTexaco, 2002 used a Screen Efficiency (SE) Test to determine sand control efficiency of several screens for SAS and gravel packed completions. Screen M performed better than other screens in the laboratory, it took longer to plug; therefore it was selected for use. The field being studied was the Boscan field in Venezuela and it was an unconsolidated formation with high viscosity crude oil, which produced sand at low drawdown of 100 – 400 psi. The SE test is described by Underdown and Sanclemente, 2002. When a fluid with similar particle size distribution of solids as the formation, is pumped through the screen, the amount of solids that pass through the screen and time taken for the screen to plug up are measured.

Mean opening in the mesh of screen M was about 225 microns and it had an average inflow area of 8 – 18 %. During the laboratory test, gravel packs provided better sand control while screen M let some sand through, but screen M was selected because it allowed the required production and artificial lift. After field application, it was observed that both screen M and gravel packs produced some very fine sand and produced about the same amount of oil. However, screen M was picked as the preferred sand control completion because it was less expensive than gravel packs.

Hodge et al of Conoco Inc. and Constien and Associates, 2002 did note that fines and uniformity coefficient affect the performance of an SAS completion. However they were able to select candidates for SAS that were shallow, low pressure, horizontal, open-hole gas wells with D_{50} of 30 microns and 49 microns. Permeability was lower than required at 50md or 250md under 1000psi net confining stress. To achieve this goal, they engaged in a rigorous laboratory testing program using whole core, sidewall core samples and other types of information that were carefully collected to ensure that the sand quality in the producing interval was represented in terms of PSD and mineral content. Selection of the DIF and clean up system to remove the filter cake was also important.

McPhee and Enzendorfer, 2004 revealed successful sand control using a suite of solutions for high-rate gas wells. Solutions were applied to OMV's Sawan wells in a HP/HT, sour gas, heterogeneous reservoir with thin, weak layers in Pakistan. The process was to log the well at total depth (TD), decide on sand control, then complete the well and perforate. Sand control method was by internal gravel pack (IGP) or selective perforation for thin, weak layers. Fuzzy logic computing correlated wireline log responses to core measurements. This provided a sand prediction tool throughout the reservoir intervals. Coupled well performance and geomechanics models determined if selective perforation could safeguard well deliverability.

Fuzzy logic computing provides tolerance for imprecision and gives some rapport with reality. Fuzzy logic is an extension of multivalued logic (Zadeh, 1988). It also includes probability theory. Fuzzy logic can apply approximate modes of reasoning. A fuzzy logic computer may process linguistic inputs e.g., more small, less small, small, large, etc. It consists of a fuzzy memory, set of inference engines, MAX block and defuzzifier which gives a crisp output.

Sawan 7 produced some sand, but stopped producing sand when the well was beaned up more slowly (hours rather than minutes). Development well test results showed that wells produced up to 100 MMSCFD, sand-free. Wells that had underbalanced coiled tubing perforation had lower skin than wells with overbalanced wireline conveyed perforation. Wells perforated with high shot density had lower turbulence skin coefficients, low permeability led to high turbulence skin. Carefully planned clean up and drawdown maintenance were part of the sand management program. Sand production from a weak interval could be controlled by improved bean up management. Well performance modeling predicted that high risk sand production zones could be shut off using a casing patch or expandable liner without affecting well productivity greatly. These sand management steps were applied to cased-hole completions, however, some of these efforts may be useful for open-hole completions also.

Ratterman et al, 2005 described the application of an inflow control device by Norsk Hydro and Baker Oil Tools, in an extended reach, open-hole, horizontal, oil well. The well is located in the Troll field in the Norwegian part of the North Sea. It was integrated with a sand screen. The ICD created higher pressure in the wellbore where coning was expected, thereby reducing drawdown. Pressure in the well was reduced opposite less productive intervals, in order to pull harder. Numerical modeling and reservoir simulation allow the ICD design to be configured such that permeability variation and wellbore effects are normalized for balanced inflow from the entire interval.

The ICD has helical channels of varied length, area and number, placed to balance inflow. The spiral design minimizes erosion of the ICD by causing a low fluid velocity. By regulating flow rate, high annular flow is prevented and particles are not sorted in the annulus, which avoids “hot spots,” or localized erosion. ICDs were also run with external casing packers between zones of varying permeability. ICDs successfully delayed water production, increased oil production and enhanced sand control.

Petit, Foucault and Iqbal, 2007 wrote about Total's use of SAS in deepwater in Angola. The Girassol field is a full subsea development. The horizontal wells with open hole SAS completions had N/G up to 80% and low UC. 6 5/8" screens were placed in 9 ½" open hole to facilitate SAS installation. Laboratory tests to observe the shale/ blank annulus showed creeping of the shale and natural shale isolation was achieved, therefore ECP's were not used as initially planned. Wrap on pipe WWS were positioned in good sands identified from LWD logs while non-reservoir sections were blanked. After 5 years, the wells were producing with PI as expected and had no sand problems. The wells with high mechanical skin have a downhole ball valve that was not completely opened or they were wells that had high mud losses.

Mathisen et al, 2007 of Hydro Oil and Energy, recommended a sand control selection method for screens, based on particle size distribution (PSD), screen tests and fluids qualification. Hydro Oil and Energy have successfully used about 230 SAS completions for long horizontal and multilateral wells in the North Sea. Water depth in the North Sea is between 150 and 1200 feet. Of the 230 screens installed, 14 failed. 80% of the screens are premium screens. Over 50% of the screens are integrated with ICD's. In one field with some of the earlier SAS wells (all of them with WWS), eight out of nine wells suffered from low productivity and sand production.

The failures were linked to mechanical damage to the screen during installation, completion fluids, long shale sections and high fines content. Other failures were caused by high drawdown and running screens in drilling mud. Efforts to increase success of the SAS completion included careful design of drilling and completion fluids; isolation of shale sections and reducing the number of swell packers to lessen the weight of the completion string. Tiffin and Bennett's guidelines are relevant, as well as the company's in-house database of PSD data and sand control design.

Adams et al, 2007 in cooperation with ConocoPhilips, described tests on sand retention media for plugging potential, solids retention, burst and collapse at downhole performance conditions. They found that published screen burst and collapse ratings were not always equivalent to actual screen performance. Welds and metallurgy varied in some locations and that affected screen performance. Laboratory tests tried to identify appropriate screen metallurgy for the life of the well, including initial acidizing, late-life water breakthrough and remedial acid treatments. Burst and collapse ratings of the sand retention layer in a premium screen should be that of the sand screen, not that of the perforated base pipe only. The proper mud system for successful application of the screen had to be determined. Operators should do physical tests on sand screens to determine the real design limits and this helps them avoid purchasing sub-standard screens.

Woiceshyn et al, 2008 discussed the application of new sand control screens (developed with fusion bonded metal laminate) in open-hole steam assisted gravity drainage (SAGD) horizontal West Canadian wells in order to withstand aggressive installation loads and severe operational loads. Severe operational loads include high temperature steam and formation collapse. A new sand screen was developed with fusion bonded metal laminate (FBML) cartridges secured in the base pipe wall. It offered less reduction of mechanical strength and is cost competitive when compared to the slotted liner. Yet it offered the performance of a premium screen in sand retention. Its torsion and collapse strength was 4 times that of a slotted liner.

The FBML cartridge screen with 20% open flow area and 132 holes per foot was called flush absolute cartridge system (FACS). Computer material models were used. The maximum gap between the FACS disc and the blank pipe, observed for thermal tension and compression was acceptable. The 102 microns observed for additional strain, was all right given that West Canadian wells in general had a higher serviceability limit of 300 microns. Acceptable screens were those that reached a load limit before the gap was at the serviceability limit. Collapse and burst performance were all right for the SAGD application. Future work would be to quantify localized strain and the phenomena that cause it; in order to address the issue of the FACS opening more with additional strain at the end of a thermal cycle.

Safin et al, 2011 of PETRONAS, wrote about their deployment of SAS in deviated and horizontal wells with poor sorting, high fines and non-uniform particle size distribution. The field is a small oilfield offshore Borneo, at water depth of 178 ft. Solution gas is the main drive mechanism and water cut development was not expected to be an early problem. 11 development wells were completed and put on production in November 2008 and have been flowing till date with higher PI and less skin than nearby gravel-packed wells. Integrated tools include swellable packers for zonal isolation, dual strings, sliding sleeves and a tube-type ICD to even out inflow and minimize annular transport of solids. Mechanical circulating sleeves were placed below the anchor packer to increase the circulating rate when displacing to the breaker fluid system. Simulation software was used to model the running of the completion string down hole.

CHAPTER 3

METHODOLOGY

Technical approach

This project involved collection and evaluation of information about wells, their completions and important factors that affected the success or failure of the completion jobs. As a result, the operator could make better plans for future well completions that would be effective and economical. Steps taken include:

- Write down project outline and timeline
- Understand problem
- Propose solutions
- Identify resources
- Stakeholder analysis
- Aggressively engage stakeholders and extract information
- Regular communication with stakeholders and review of project objectives
- Assemble, analyze and present results
- Continue evaluations, tests, execute completion jobs, share lessons learned.

CHAPTER 4

ANALYSIS AND RESULTS

Field A: This reservoir is an unconsolidated sandstone. SAS: A 19, unintentional SAS: A 14.

Table 5.1 SAS Well Status in Field A.

	A 14	**A 19**
Unintentional SAS (ft MD)	3038 ft of SAS assembly, 100 % of open hole	495 ft of SAS assembly, 100 % of open hole
Oil production (bopd)	7800 bopd in 2006, about 5000 in 2010, now intermittent, no injector support	About 4000 bopd in mid 2009, now intermittent, no injector support
Sand production	Minimal, acoustic signals same as OHGP wells, rising water cut in 2009 and slightly higher acoustic signals in late 2009	Minimal, acoustic signals same as OHGP wells
Fines		
PI (bpd/psi)	Aug. 2008 was 110. Average PI for the 2 SAS wells was 299 bpd/psi in 2008, similar to horizontal OHGP wells at 302.	Aug. 2008 was 190. Average PI for the 2 SAS wells was 299 bpd/psi in 2008, similar to horizontal OHGP wells at 302.
Age (yrs)	5.5	5.5

Table 5.2 Selection Criteria in Field A

Criteria	The operator	A 14	A 19
UC	More conservative than well parameters	3	3
Fines		4.6%	4.6%
D_{50} (μm)		198	198
Sand N/G		83%	100%
Geologic N/G		60%	60%

Important factors: include PSD, fluids, stability, laboratory tests on screens, controlled operations, pore pressure - fracture pressure window, water depth.

Stability is important because in some wells, due to the likelihood of the formation/ shale sections becoming unstable and moving into the hole, it is possible that an open hole gravel pack (OHGP) job could end up as incomplete.

Similarly, if the **pore pressure – fracture pressure window** is narrow, then the gravel carrier fluids might easily be lost and the OHGP could end up as an incomplete job.

A 14 was started up as a producer on 28th December 2005. Its screen is a 230 microns 5.5" Excluder premium screen in 8.5" open hole. It has experienced declining production due to water breakthrough with water cut at 28% and also because of declining injectivity in its injector well. A 19 was started up as a producer on 27th December 2005. Its screen is a 230 microns 6 5/8" Reslink WWS in 8.5" open hole. A 19 was shut-in in May 2009 due to high BS&W of 60% (injected water raised this to 80% before). Another reason for the shut-in is that injection in A 20 ceased. A 14 and 19 are now producing intermittently. Water broke through in 2007 in both wells and then average PI dropped to about 150 bpd/psi. Shales are isolated with blank pipes in the wells.

Field B: This field has unconsolidated sandstone. Unintentional SAS from incomplete gravel packs.

Table 5.3 SAS Well Status in Field B.

	WELL 1	WELL 2	WELL 3
Unintentional SAS (m MD)	78.5% Alpha Wave Cover, therefore top of screens exposed over full 850m open hole length. (172 m of blanks, 610 m of screens) Approximately 21.5% of open hole has SAS.	Alpha Pack - 45% From 9 5/8" Shoe, Therefore top of screens exposed over full length (804m of screens and blanks). 55% of open hole has SAS.	38% Alpha Wave Cover. Therefore top of screens exposed over full length (611m of screens and blanks). 62% of open hole has SAS.
Oil production (m3/d)	1518.8	1771.7	226.6
Sand production (kg)	~0	~0	~0
Fines (kg)	~0	~0	~0
Skin	0.1	0.13	3.2
Age (yrs)	2	1.5	1.5

Table 5.4 Selection Criteria in Field B

Criteria	The operator	Field B	WELL 1	WELL 2	WELL 3
UC	More conservative than well parameters	11-15			19
Fines		10 - 34%			4.5%
D_{50} (µm)		143 - 502			1681
Sand N/G		83 – 91%	84%	83%	91%
Geologic N/G		50 – 69%	50%	69%	68%

Field B's WELL 1 well was the first openhole operation so no blanks were placed along the screened length. WELL 2 and WELL 3 were fitted with blank pipes aligned with the shale sections. Field B data is from cores and WELL 3 data is from drill cuttings. The cuttings analysis took a few months and was not done on site. Shales are isolated with blank pipes only in some of the wells. The wells have 5.5” Poromax screens in 9.5” open hole with some gravel.

Analysis of Field B’s production data:

WELL 3 – Impairment has been observed. (Skin estimated at 3.2, from initial estimate of 0.1).

WELL 1 – Very slight increase in skin over time (from -0.1 mechanical skin to +0.1).

WELL 2 – Very slight increase in skin over time (from 0.01 mechanical skin to 0.13).

Gas is flowing from a gas disposal well through WELL 1 to surface. Water has broken through in all 3 wells and is up to 40 %.

WELL 3 has higher skin and lower productivity than projected. This problem increased over time. It also has a water cut that has risen to 30-40%. Diagrams from the caliper log show enlarged hole in about 62 feet of shale opposite the blank pipe. The question exists about the cause of the higher skin. Is the shale smeared onto the screen and restricting flow or do we have relative permeability that is changing to assist water flow more than oil or are fines migrating with the water?

Field C and Field D

Unintentional SAS wells from incomplete open hole gravel packs.

Table 5.5 SAS Well Status in Field C and Field D.

	WELL 4	Well 5
Unintentional SAS (m MD)	348m of SAS assembly, 95 -100% of open hole has SAS.	602m of SAS assembly, 80% of open hole has SAS.
Oil production (bopd)	8500 bopd in 2006, about 5000 in 2010, now shut in due to scales.	10000 bopd in 2008. Now about 1500 bpd with gas lift. High water cut of 90%.
Sand production (kg)	~0	~0
Fines (kg)	~0	~0
Age (number of producing yrs)	4	7.5

Table 5.6 Selection Criteria in Field C and Field D

Criteria	The operator	Field CX core	Field CY core	WELL 4	Well 5
UC	More conservative than well parameters	13.92	32.11	13 – 32	High
Fines		20-25%	30-40%	20 - 40%	High
D_{50} (μm)		226.1	131.2	131- 226	
Sand N/G					
Geologic N/G		>=95%	>=95%	>=95%	94%

Data is from Field CY and Field CX GSD. Field CX is in the channel while Field CY is in the lobe. Shales are isolated with blank pipes only in the wells. Well 4 screen: 6.033" OD, 210 micron Poromax in 8.5" hole. Well 5 screen: 5.5" OD ELP 16/30 pre-pack 0.012" gauge and 5.5" OD 250 micron Poroplus. Hole ID: 8.5" Centralizers were used in both wells.

Well Status: WELL 4 has problems of water cut = 30% and is now shut in due to $BaSO_4$ and $CaCO_3$ scale. Well 5's rate was 10000 bpd up to mid-2008, when water cut started at 10%.

Table 5.7 Other Factors that Affect the Application of SAS:

Successful SAS wells	Unsuccessful SAS wells
Preliminary tests on screen: Constien tests, The operator's tighter test QA/QC. Mechanical tests for burst, collapse, tension, compression, temperature, fluids. Planning for the life of the well.	Water break-through: removes capillary forces and cohesion between grains. Compaction drive could lead to screen damage.
Enhanced N/G: blanks, swellable SAS like the Petroguard, swellable or mechanical packers. Swellables can be time delayed.	Movement of shale onto the screen.
Wellbore stability: SB DIF and non-aqueous completion fluid, minimize open hole time, adequate mud weight.	Thinly interbedded shales, heterogeneous reservoirs. Damaged formation.
In-gauge hole from drilling: rotary BHA, hole cleaning, weight on bit, updated geomechanical models and stresses.	High fluxes. Flux is usually limited to a few feet per second or BOPD/ft, especially for unconventional candidates for SAS (Bennett et al, 2000).
Controlled operations, low drawdown.	High stresses after depletion. Pressure maintenance can reduce this problem.

Constien Oil Flow Test flows a volume of slurry through a screen only system or a screen with differing gravel pack media, at a constant drawdown under confining stress. The simulated formation slurry has particles similar to the formation's PSD. Initial permeability and final permeability are measured. Desired performance is:

1. Solids Production (@ 3 gal/ft^2) – less than 0.12 lb/ft^2; Martch, 2007.

2. Retained Screen Permeability – 50% or greater.

3. Maximum Sized Produced Particles – 44 micron.

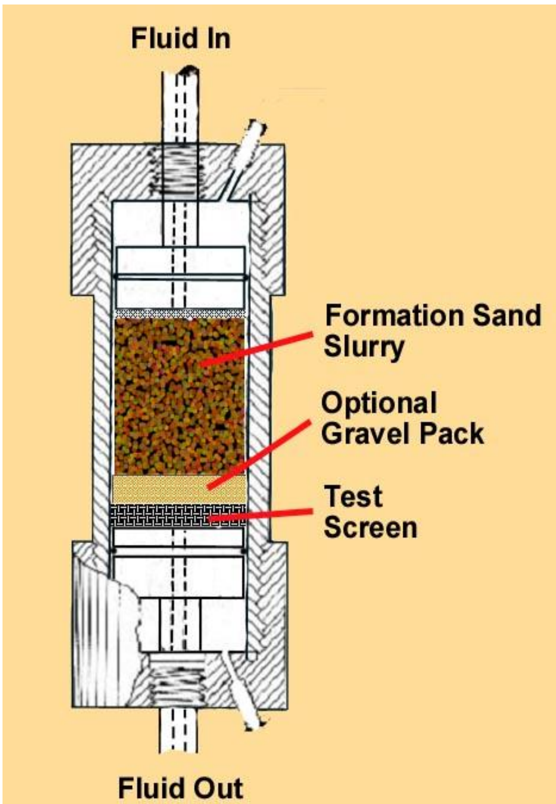


Figure 5.1 Constien Oil Flow Test Method (Martch, 2007).

Controlled Production Operations that lead to success include:

- Planning and modeling to select operating envelope.
- Tremendous attention to detail and traceability on screen QA/QC.
- First months of production: Field B ESPs were not used to prevent damage to the completion.

- ESPs were later used in an optimal fashion and contingency planning was done for pump failure.
- Focused surveillance using Pressure Transient Analysis, down hole pressure and temperature gauges (DHPTG), multiphase flow meters (MPFM), acoustic sand detectors.
- Gradual increase in drawdown by 50 psi or 1000 bpd per 24 hours. Limited drawdown. For instance, in the Field A 690 reservoir, the maximum drawdown was 450 psi.

<u>Contingency Planning in an SAS job</u>

General steps for installing the SAS:

1. Drill and case the production casing section. Perform wellbore clean out (WBCO) and scrape across packer setting area.
2. Drill open hole section with synthetic based drill in fluid (DIF).
3. Circulate to solids free invert water in oil emulsion in open hole and solids free brine above it, (emulsion, then $CaCO_3$ brine – back-up LCM measure, and brine towards surface).
4. Locate screens on depth. Operations may include circulation if full length wash-pipe has been employed.
5. Set packer.
6. Isolate and test packer.

7. Retrieve setting tool and close and test fluid loss valve, to isolate formation.
8. Pull out of hole (POOH).
9. Run upper completion. Stab it into or interface with packer. Set packer and test sub-surface safety valve.
10. Install subsea Christmas tree. Shut in well until ready for production.
11. Open fluid loss valve from host and flow back to surface.

Table 5.8 Contingency Planning in an SAS Job.

Risk	**Prevention/ Response**
Screen stuck with blanks opposite pay	Perform torque and drag analysis on hole section with screens and centralizers to be used. Normalize friction factors against actual for future reference. Check for formation and shale's reaction to fluids before using them. Be careful with screen OD. Do proper hole cleaning. In-gauge hole. Response: Clean hole and POOH. If stuck, set packer, POOH, plug, sidetrack.
Filter cake or completion fluid plugs screen	Be careful with shaker screens and solids sizing in SB DIF. Production screen test (in laboratory or on location) on DIF. If it doesn't pass the test, treat the mud some more. Invert emulsion completion fluid that could flow back to surface. Response: inject and flow back; last resort: side track.
Change in completion dimensions	Make sure extra joints, blanks and packers are supplied on location in case open hole and completions lengths adjust, based on logs or other factors.
Loss of well control	Adequate emulsion and brine wt and filter cake. Brine should not be denser than emulsion. Response: Close BOPs (2nd

Table 5.8 Contingency Planning in an SAS Job contd.

Risk	Prevention/ Response
	barrier). Circulate.
Fluid loss	Prevent with filter cake. Valve in packer is barrier with screens on bottom. Pump $CaCO_3$ LCM fluid. Filter cake may be removed with acid. Metallurgy should be able to withstand fluids, temperature, pressure.
Packer does not set	Release. POOH, run another packer with seal assembly that will work.
Packer does not hold pressure	Run another packer and fluid loss device above lower completion left in hole to avoid damage to screens. Sting into the bottom packer.
Ball valve does not close	Leave ball valve open. POOH. Run a second ball valve with tubing string.

Job precautions: Verify correct packer setting balls (and back-up) and correct connections are on location. Measure and drift all screen and blank joints. Drift each joint as it is picked up (keep only one drift on the floor and keep track of it at all times). Extra closing method: If there are high fluid losses while POOH with the service tool after shifting the flapper or valve in the packer, follow alternative procedures to close the valve. Do not put too much weight on screens to avoid damaging them. Screen size vs. hole size: close to hole ID, but avoid a stuck toolstring.

Completion Fluids in A 19 contributed to the success of the job. There was a non-aqueous water in oil, emulsion in the open-hole section with solids-free brine above it. Solids in completion fluid should cover pores but flow back through screen. After circulating to completion fluid, the fluid, filter cake and BOPs maintain well control until screen and packer are set on depth. Avoid delays before running the screens to prevent hole collapse. Issues to consider when using a brine above invert emulsion include

- Make sure the density of both fluids is the same to avoid the brine flowing past the emulsion;
- Fill the screens while running in hole (RIH): the Field A SAS had a valve at the bottom of the workstring so that it could fill itself as it was run down hole. Therefore, the fluid in the screen was emulsion in the open-hole section of the well.
- If possible, check the reaction of fluids with shale samples from within the sand column. The shale samples may be obtained from cores or drilling cuttings.

CHAPTER 5

CONCLUSIONS

6 out of 7 operator wells had successful SAS (no sand production and good oil flow as expected). This is an 85% success rate.

Table 6.1 The Operator's Criteria vs. Well Parameters in Detail

Criteria	The Operator	A 14	A 19	Field B core	WELL 3	Field CX core	Field CY core	Well 5
UC = D_{40}/ D_{90}	More conservative than well parameters	3	3	11-15	19	13.92	32.11	High
Fines		4.6%	4.6%	10 - 34%	4.5%	20-25%	30-40%	High
D_{50} (µm)		198	198	143 - 502	1681	226.1	131.2	
Sand N/G		83%	100%	83 – 91%	91%			
Geologic N/G		60%	60%	50 – 69%	68%	>=95 %	>=95 %	94%
Oil production		About 5000 bopd in 2010, now intermittent, no injector support	About 4000 bopd in mid 2009, now intermittent, no injector support	WELL 1: 1518.8 m3/d, WELL 2: 1771.7 m3/d	226.6 m3/d	Well 4: 5000 bopd in 2010, now shut in due to scales.		10000 bopd in 2008. Now about 1500 due to water cut.
Sand production		Minimal	Minimal	~0	~0	~0		~0

Shales are isolated with blank pipes in some of the wells. Continue well surveillance to see how the wells perform over the years.

<u>Recommendations</u>

The operator's Completion Engineers provide a comprehensive Well Handover Certificate at the conclusion of well construction that is provided to the asset team. This is a live document that documents the well status at handover. This document can be further populated with additional pages to provide feedback on well performance, after host commissioning of the well, and periodically over the well life.

The operator's current selection criteria are quite conservative and should be adjusted as long as the SAS are physically tested first with a laboratory model to validate use of the SAS in such wells. This statement is supported by the fact that there are wells that produced oil as expected without sand problems. Some of those wells had rigorous retention tests done on the screens and gravel packs before running the completion. Some of the completions were designed for the worst case such that the screen slots would be smaller than the D_{10} as is required for an SAS completion. Other operators that have chosen non-traditional candidates have also done extensive tests using representative formation samples.

Wellbore stability, enhanced N/G and controlled operations are necessary to achieve success with future SAS wells. A risk assessment that quantifies and adds up the risk would help with decision making. The opportunity exists to save $6-8 million per well, but consider risks as well as cost carefully before selecting a sand control method.

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LIST OF ABBREVIATIONS

Cr	chromium
$BaSO_4$	barium sulphate
BHA	bottom-hole assembly
BOP	blow out preventer
Bopd	barrels of oil per day
Bpd	barrels per day
BS&W	basic sediments and water
$CaCO_3$	calcium carbonate
CH HRWP	cased hole high rate water pack
CHFP	cased hole frac-pack
CO_2	carbon dioxide
DHPTG	down hole pressure temperature gauge
DIF	Drill-In-Fluid
Dir	direction

ECP	external casing packer
EGP	external gravel pack
ELP	enhanced low profile
ESP	electric submersible pumps
ESS	expandable sand screen
FACS	flush absolute cartridge system
FBML	fusion bonded metal laminate
Ft	feet
Ft ah	feet along hole
GSD	grain size distribution
HP/HT	high pressure/high temperature
Hz	horizontal
Hz OHGP	horizontal open hole gravel pack
ICD	inflow control device

ID	inner diameter
IGP	internal gravel pack
Inc	inclination
JIP	Joint Industry Project
LCM	lost circulation material
LWD	logging while drilling
Md	millidarcy
MD	measured depth
MPFM	multiphase flow meter
N/G	Net/Gross
OD	outer diameter
OFA	open flow area
PI	productivity index
POOH	pull out of hole
PPS	pre-packed screen
PSD	particle size distribution
Psi	pounds per square inch

QA/QC	Quality Assurance and Control
RIH	run in hole
SAGD	steam-assisted gravity drainage
SAS	Stand Alone Screen
SBDIF	synthetic based drill-in-fluid
SE	screen efficiency
Synth	synthetic
TD	total depth
UC	Uniformity Coefficient
WBCO	wellbore clean out
WBDIF	water based drill-in-fluid
WWS	wire-wrapped screen
Yr	year