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Understanding and Overcoming Challenges in Sand Control for Oil Extraction

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Abstract

In the petroleum industry, sand production is a prominent technical and economic challenge that may lead to severe implications such as well abandonment and casing erosion. This challenge is particularly pronounced in unconsolidated reservoirs. The present study offers a thorough examination of sand production, detailing its causes, monitoring techniques, and detection methods. It further delves into the various measures implemented to mitigate the impact of sand production. A unique emphasis is laid on sand screens, recognized for their cost-effectiveness and efficiency in controlling sand production. This paper discusses the different categories of sand screens, highlighting their critical role in accomplishing successful gravel-packed completions. Moreover, it explores the real-world application of sand screen techniques in sand-producing reservoirs. Through these findings, the research provides invaluable insights into sand control methods, underlining the integral role of sand screens in optimizing operations within the petroleum industry.

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1. Introduction

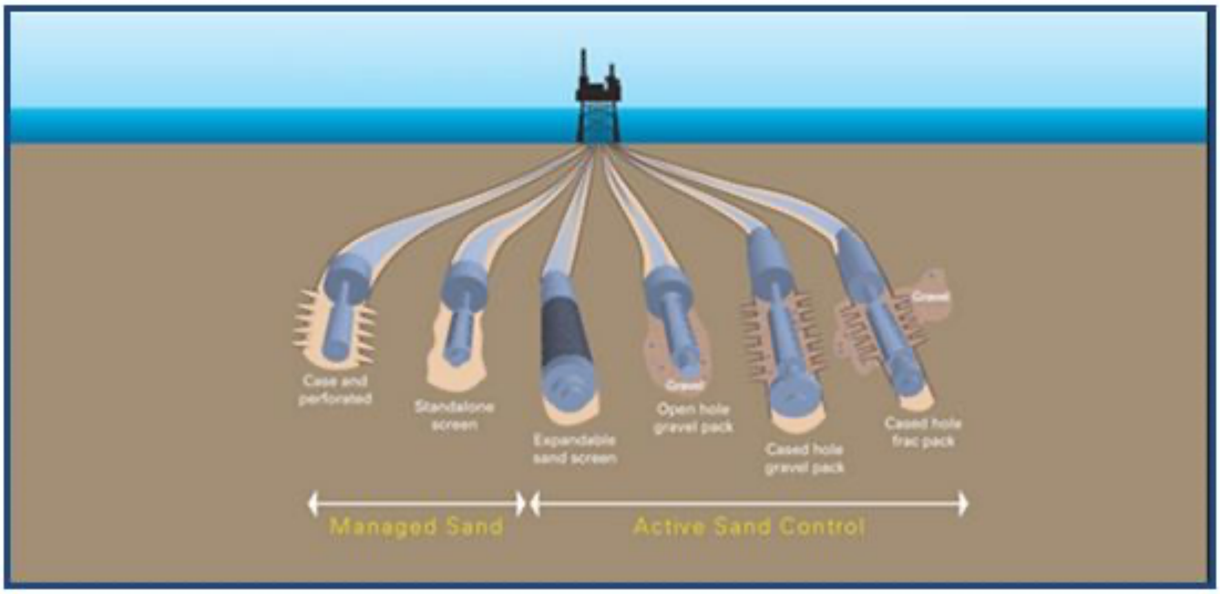


Figure 1:Sand Control Types (UK Essays, 2018)

In the realm of oil and gas extraction, substantial knowledge and years of experience have led to the development of completion techniques specially designed for unconsolidated and fragile reservoirs, such as those prone to sand production (Bellarby, 2009). Sand control options come in various forms, including open and cased-hole completions, each tailored to suit specific reservoir characteristics and field experience (Bellarby, 2009). Despite their common use, implementing these sand control strategies can be technically challenging and financially costly, underscoring the need for strategic planning (Bugachev & El-Dabi, 2011).

Sand control, particularly downhole sand control, plays a pivotal role in reservoirs prone to sand production. It mitigates the risk of excessive sand production over time, which could otherwise lead to significant operational problems (Bellarby, 2009). Should sand control efforts falter, the consequences could be severe, such as the reservoir pressure falling below the water gradient, necessitating costly and time-consuming intervention (Bugachev & El-Dabi, 2011).

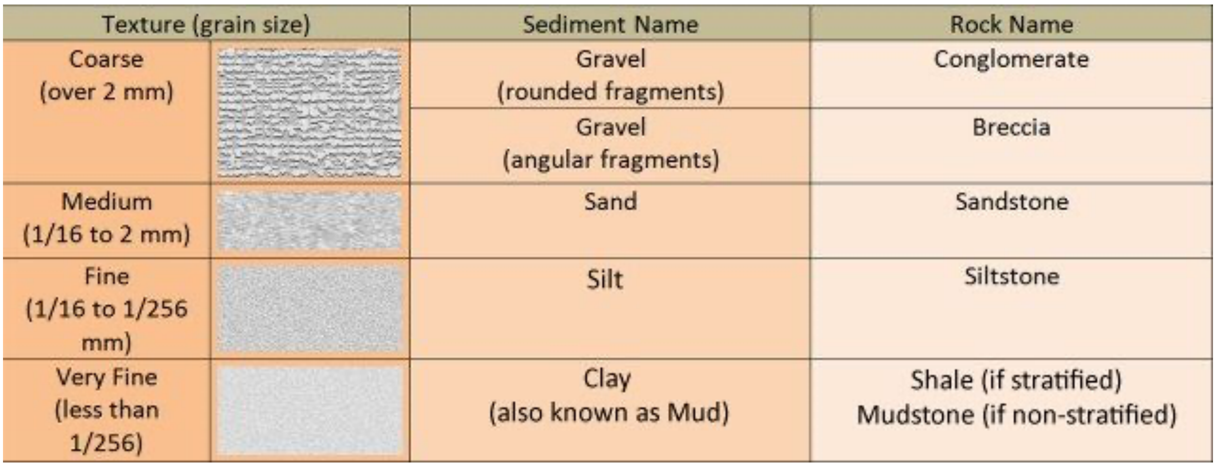
The process of designing an optimal sand control strategy and managing sand production is complex and multifaceted. It involves a range of factors including geographical considerations, technical variables, and economic constraints, requiring the careful navigation of industry professionals (Heriot Watt University, 2016). Key technical variables that influence the selection of sand control strategies include the exclusion type, rock pack size, pre-packed screen, space width, liner space length, and productivity index reduction. Each of these elements interplays with the others, thereby adding further complexity to the decision-making process (Heriot Watt University, 2016).

Despite these complexities, sand control completions have proven to be reliable in managing sand production, particularly in unconsolidated formations, and are thus widely adopted within the industry (Ott & Woods, 2003). Among these strategies, the installation of sand screens in sand reservoirs is a standard practice, which, when executed correctly, can yield satisfactory results (Ott & Woods, 2003). However, the application of sand screens in depleted reservoirs is less common due to their unique challenges. Achieving successful outcomes in such reservoirs is considered a notable achievement in engineering and technology (Bugachev & El-Dabi, 2011). Therefore, careful selection of sand screen types and techniques is of paramount importance for realizing improved and desirable results in depleted reservoirs (Ott & Woods, 2003).

This thesis delves into the complexities of sand production, elucidating its associated challenges and prevalent control measures, with a particular emphasis on the application of sand screens in sand-prone reservoirs. An in-depth examination reveals how sand production detection and monitoring techniques are integral to mitigating risks in the petroleum industry. Furthermore, a comprehensive analysis of sand control techniques offers valuable insights into their effectiveness in managing sand production. In navigating these complexities, the transition into a more detailed discussion of sand production and its characteristics is crucial. As such, this work ultimately provides a holistic understanding of sand production, control methods, and their far-reaching implications in the realm of petroleum engineering, laying the groundwork for an in-depth exploration of sand production itself in the following sections.

2. Sand Production and Its Geological Context

Sand, a sedimentary material with a mean grain size of 0.0625 mm to 2 mm, serves as the building block for sandstones when compressed and cemented (Matanovic, Cikes, & Moslavac, 2012). Sandstones, notable for their high porosity and permeability, constitute significant reservoirs for sedimentary hydrocarbon reserves (Matanovic, Cikes, & Moslavac, 2012). Although most oil and gas deposits exist in sandstones or carbonates, exceptions can be found in rocks such as shale, igneous rock, and shattered basement rock. However, these are less prevalent than sandstones or basalt (Matanovic, Cikes, & Moslavac, 2012).



Texture (grain size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (rounded fragments)	Conglomerate
		Gravel (angular fragments)	Breccia
Medium (1/16 to 2 mm)		Sand	Sandstone
Fine (1/16 to 1/256 mm)		Silt	Siltstone
Very Fine (less than 1/256)		Clay (also known as Mud)	Shale (if stratified) Mudstone (if non-stratified)

Figure 2: Rock classification (CivilsDaily 2016)

2.1 Classification and Risk Assessment of Sand Production

The risk assessment of sand production incorporates several techniques, from geological formation comparison and core examination to well testing and log interpretation, supported by field experience (Bellarby, 2009). Understanding rock types prone to sand production is crucial. For instance, sandstones and shale each possess unique characteristics that can contribute to sand production.

2.2 The Brinell Hardness Number and Sand Production

Traditional rock classification in geology relied heavily on visual and physical testing methods (Heriot Watt University, 2016). However, a more objective approach was proposed by Van der Vills (1970) with the introduction of the Brinell Hardness Number (BHN) for rock categorization, a measurement determined by applying a static load to a steel ball pressed onto the material's surface (Heriot Watt University, 2016).

This method has proven particularly valuable in the study of unconsolidated, partly consolidated, and friable sands — all of which have a significant propensity towards sand production (Bellarby, 2009). These sands are common in shallow, young unconsolidated rocks, generally no deeper than 8000 ft (approximately 2400 m) and originating from the Miocene-Recent period (Bellarby, 2009).

Quicksands, a subset of problematic sands, pose a challenge due to their lack of cohesive force and compactness. Their instability can lead to issues during drilling as they may collapse into the wellbore (Bugachev & El-Dabi, 2011). On the other hand, competent uncemented sands display some natural cohesion due to the increased in-situ stress with depth (Bellarby, 2009). This provides enough internal friction to keep the wellbores open during various operations, although the absence of sand control measures can still lead to continuous sand production (Bellarby, 2009).

2.3 Considerations in Sand Production: From Consolidation to Friability

Aside from hardness, the lithological formation from which oil or gas is extracted plays a crucial role in sand production. For example, unconsolidated rock formations lack a binding agent to keep the rock particles together, making them more prone to sand production under stress (Bellarby, 2009).

Partially consolidated sands present another challenge as they contain weak cementing agents that give them a weak unconfined compressive strength. These sands, while they can often be extracted with conventional core barrels, are prone to crumbling (Bellarby, 2009). Friable sands, despite their initial robust appearance, can fail due to the combined effects of stress, erosion, and changes in saturation. This often results in intermittent periods of sand production. While the issue may decrease over time, it can recur under certain conditions, such as significant decreases in pore pressure or water inflow into the well (Bellarby, 2009).

In contrast, consolidated and hard rocks are typically less prone to sand production, barring initial cleanup and testing of poorly completed wells (Bellarby, 2009). Any initial sand release from drill stem test (DST) tools during testing is usually due to the release of porous materials from rock and soil pore spaces, or stabilizing substances applied during wellbore cleanup and stabilization operations (Bellarby, 2009). Notably, the initial drawdown phase often contributes to an increase in cavity volume (Bellarby, 2009).

Finally, quicksands, which are a unique type of unconsolidated sands, are characterized by high porosity and permeability, with the lack of a cementing agent. This lack allows easy fluidization under the influence of upward-flowing water, creating unique challenges in oilfield operations (Bugachev & El-Dabi, 2011).

To summarize, the classification and understanding of rocks in relation to their propensity for sand production is vital for effective sand control. This understanding informs the choice of sand control techniques and equipment, which can range from simple measures like installing sand screens, to more complex solutions such as gravel packing and resin coating. As such, taking the different types of sands and their properties into account can greatly improve the process of hydrocarbon extraction.

2.4 Causes of Sand Production

The occurrence of sand production during oil and gas extraction can lead to significant operational complications and subsequent costs. An in-depth understanding of the causes, impacts, and potential remedial strategies for sand production is, therefore, essential for the preservation of the overall extraction system, which includes surface gathering systems, separating devices, and disposal mechanisms (Matanovic, Cikes, & Moslavac, 2012; Bellarby, 2009).

Accompanying hydrocarbons, sand production necessitates additional handling procedures, leading to an increase in costs. Furthermore, sand production can have deleterious effects on the involved geological formations. For instance, the loss of solid materials can disrupt the structural stability of the reservoir, creating potential challenges for maintaining wellbore stability (Matanovic, Cikes, & Moslavac, 2012; Veeken & Davies, 2000).

Mitigating these issues may involve the deployment of various strategies. These include conducting geomechanical assessments for a detailed understanding of rock properties, optimizing well parameters such as drawdown pressure to minimize sand mobilization, implementing selective perforation techniques to bypass sand-prone zones, and modifying production strategies to reduce sand output (Matanovic, Cikes, & Moslavac, 2012; Ekechukwu & Nwoke, 2013).

The onset of sand production can be traced back to several interconnected causes, including the mechanical breakdown of reservoir rocks, anthropogenic activities like aggressive production strategies, or natural geological processes. These causes can create a balance between the forces acting on sand grains, influencing the overall volume and rate of sand production (Matanovic, Cikes, & Moslavac, 2012; Papamichos & Muehlhaus, 1995). This concern is particularly pronounced in younger, unconsolidated geological formations with loosely connected sand grains.

Various elements can exacerbate sand production. These include a decline in reservoir pressure, an increase in water production or cut, fluctuations in flow rates, viscosity changes in the produced fluid, and the nature and volume of cementing substances that hold the sand grains together (Matanovic, Cikes, & Moslavac, 2012; Osisanya & Ertekin, 1996).

The effects of sand production can manifest in different ways, resulting in both downhole and surface problems. Some wells might experience transient sand production, which decreases over time as the most mobile sand grains are produced. In contrast, some wells may encounter continuous sand production, requiring consistent management strategies to preserve operational integrity and efficiency (Matanovic, Cikes, & Moslavac, 2012; Bellarby, 2009). A detailed understanding of the sand production behavior in individual wells serves as the basis for these management strategies.

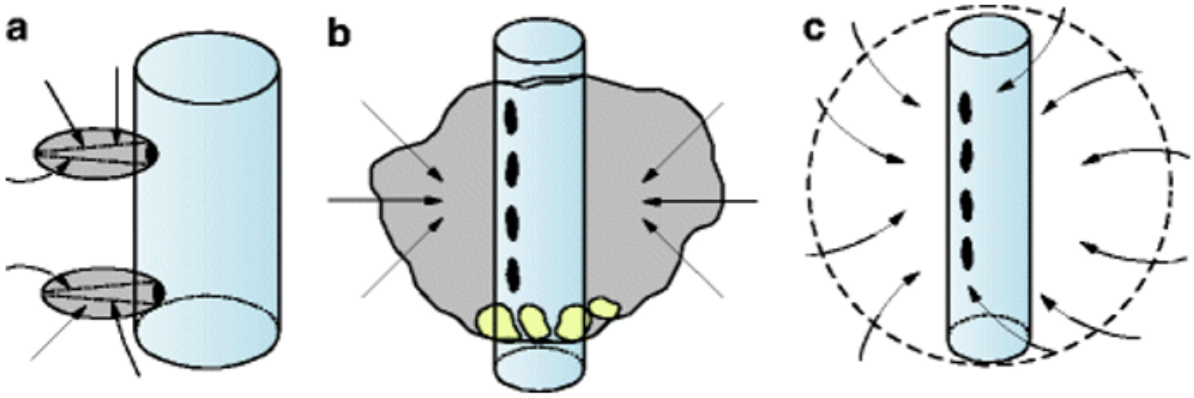


Figure 3: (a) Enlargement of perforations, (b) Formation of cavity, (c) Cavity shedding (Matanovic, Cikes, & Moslavac, 2012).

Regardless of the origin of sand production, the phenomenon can contribute to significant expansion in the wellbore (Matanovic, Cikes, & Moslavac, 2012). Upon the elimination of debris from perforations, a degree of perforation enlargement is not only feasible but also anticipated, as demonstrated in Figure 3(a) (Matanovic, Cikes, & Moslavac, 2012).

Should this enlargement continue, initially separate perforations may converge, leading to the creation of a large cavity as represented in Figure 3(b) (Matanovic, Cikes, & Moslavac, 2012). One key metric for evaluating sand production in this context is the total accumulated volume of sand over the perforated interval, which incorporates the sand deposited within the wellbore (Matanovic, Cikes, & Moslavac, 2012).

Moreover, it's important to note that formations, even those appearing wholly or partially consolidated, may be prone to periodic sloughing of sand and overburden layers. This dynamic is illustrated in Figure 3(c) and provides further insight into the complex nature and potential impacts of sand production (Matanovic, Cikes, & Moslavac, 2012). These complications require effective management strategies to ensure operational stability and efficiency in the extraction process.

2.5 Overview of Geological Conditions

Before sand control treatment can be recommended, the potential for sand production within the well must be assessed. A common approach is to review the production records of adjacent wells. If wells in the same zone have shown signs of sand production at any point, the target well may also be at risk (Bellarby, 2009).

2.5.1 Mechanical Properties Log (MPL)

In new wells at untested locations, predicting sand generation is more challenging. Laboratory core studies and Mechanical Properties Log (MPL) analysis can be used to study the formation's integrity and anticipate sand production (Bellarby, 2009; Smith et al., 2010). The MPL provides key data about the mechanical behavior of the formation, such as compressibility, stiffness, and strength. This data can indicate the formation's ability to resist deformation and fracture, thus offering insights into its potential for sand production.

The MPL analysis process begins with the extraction of cores from the formation. These samples are then tested under a variety of conditions in a laboratory to simulate the reservoir's environment. The data from these tests is used to create an MPL, where the strength and other mechanical properties of the rocks are plotted against depth (Bellarby, 2009; Liu et al., 2013).

This MPL analysis can help identify zones that are at risk of sand production. If areas are found to have low rock strength and high compressibility, engineers can anticipate the formation collapsing under production stresses, resulting in sand production. This information can guide the design and implementation of sand control measures like gravel packing, frac packing, or the use of resin-coated sands to reinforce the wellbore and mitigate sand production (Smith et al., 2010).

In conclusion, the Mechanical Properties Log analysis serves as a critical tool in sand control, providing valuable information on the mechanical behavior of the formation that contributes to comprehensive well design, thereby enhancing operational efficiency and safety.
The utilization of mechanical instruments that persistently track sand production from wells is crucial for effective sand management. Such tools provide essential data, such as when sand production initiates in a newly drilled well and the progress towards achieving sand-free production after a sand control intervention (Bellarby, 2009).

2.5.2 Core Inspection and Testing

Core inspection and testing involves evaluating representative samples from the reservoir under laboratory conditions. Whole cores, which provide the most accurate representation of the formation, are preferred for this kind of analysis (Bellarby, 2009; Abney & Griffith, 2019). This process allows for a thorough evaluation of the natural cementing material used, its water sensitivity, and any mobile fines present. It can also provide insights into their destabilizing effects on rock strength and the impact of flow and stress variations on core stability (Bellarby, 2009).

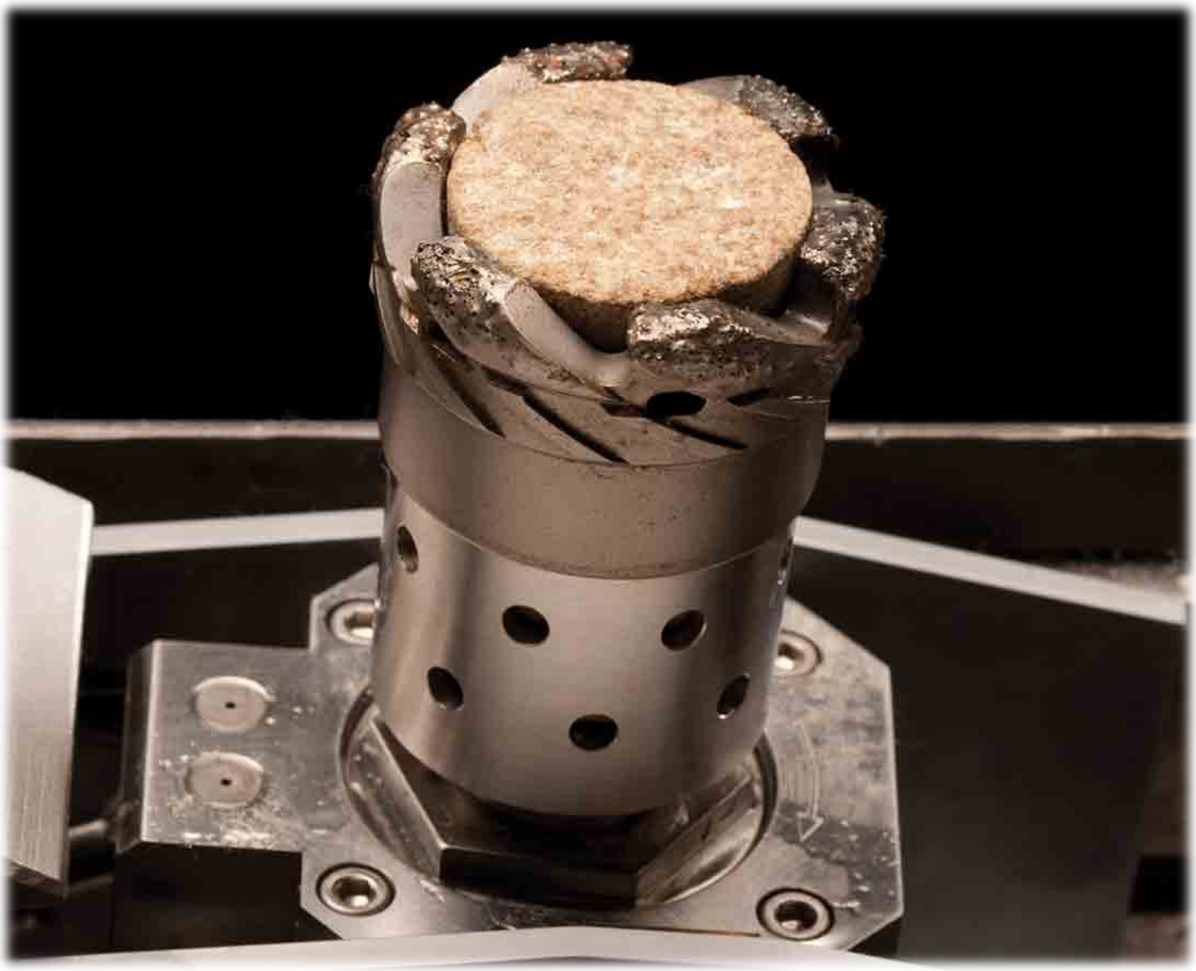


Figure 4: Figure 4: Sidewall core sample (SLB)

However, the core retrieval process can induce destressing of the core material, potentially reducing the cohesion previously provided by grain-to-grain friction, and destabilizing the formation (Abney & Griffith, 2019). Additionally, drilling fluid and subsequent handling and storage can negatively impact weak cements, such as clay (Bellarby, 2009).

The core inspection and testing program's goal is not just to evaluate the core samples but also to establish a relationship between the tested samples and untested core sections. These could include zones where core retrieval was not possible due to operational constraints (Bellarby, 2009). The data obtained from these laboratory tests can also serve as input for theoretical rock mechanical analyses aiming to provide a qualitative explanation for observed sand production behavior in Drill Stem Tests (DSTs) and production wells (Bellarby, 2009; Li & Moridis, 2005).

2.5.3 Correlation between Cementation Indicator and Drawdown

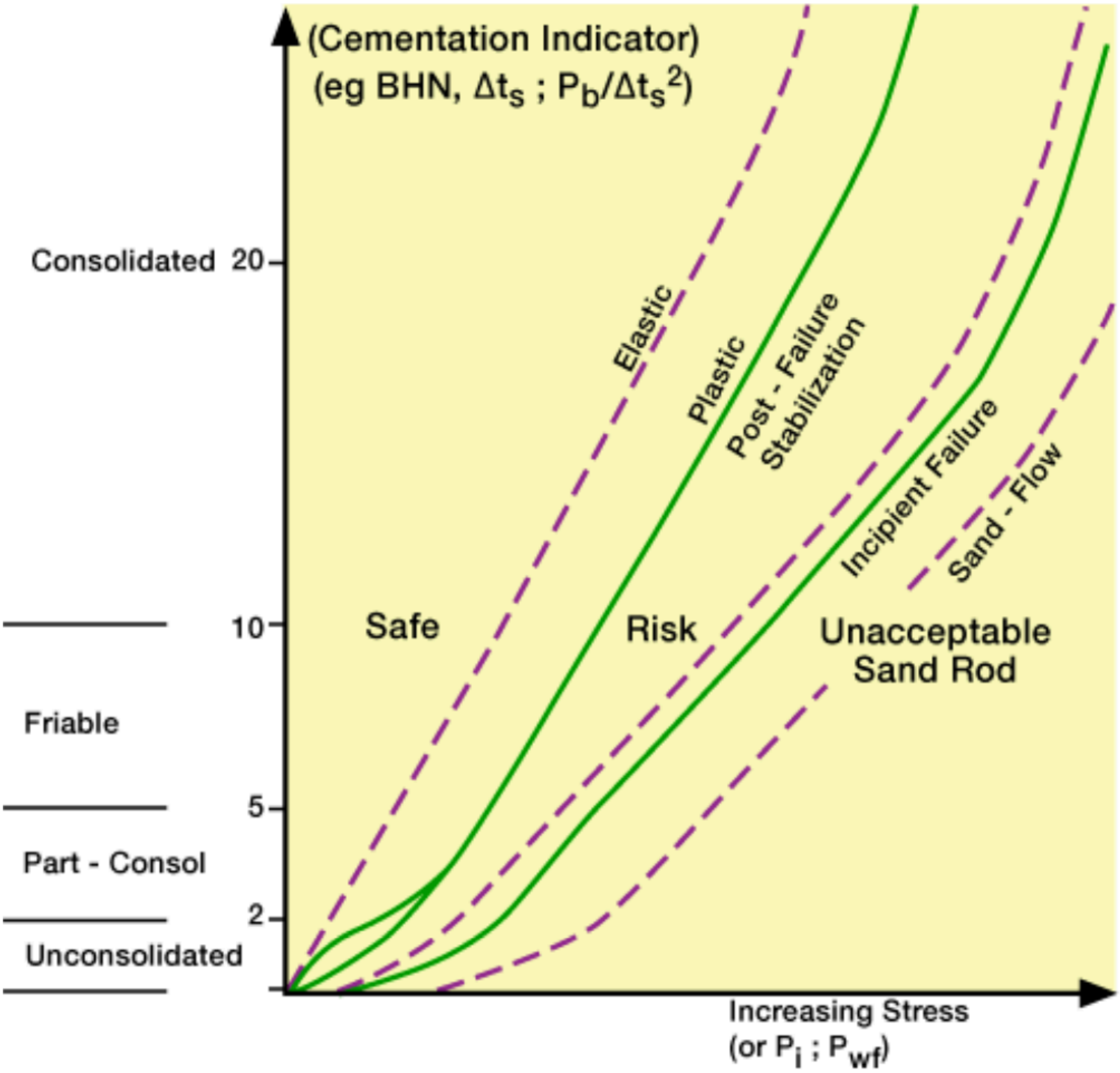


Figure 5: Illustration of the correlation between the cementation indicator and drawdown (IPIMS, n.d.).

Determining the optimal strategy for sand control involves the use of empirical techniques, each with its set of limitations and applicability to specific geological basins or regions (Bellarby, 2009). One such method, first proposed by Stein and Hilchie in 1972 while they were working at Mobil Oil, involves plotting production and test data on a graph depicting borehole-compensated sonic (BHCS) velocity versus drawdown (Stein, Hilchie, 1972;

Bellarby, 2009). This technique enables the identification of safe, risk, and failure zones associated with sand production (Morita, Fuh, et al., 1997).

Figure 5 presents the relationship between the cementation indicator and drawdown. According to the Stein and Hilchie method, sand production is anticipated when the sonic transit time (STT) exceeds a certain threshold, typically between 95 and 110 µs/ft, based on regional geological conditions (Morita, Fuh, et al., 1997; Bellarby, 2009).

An alternative approach, put forth by Tixier, uses log-derived factors of shear modulus (G) and bulk compressibility (Cb) (Tixier, 1957). The equations for calculating these parameters are as follows:

$$G = 1.34 \times 10^{10} \frac{A\rho_b}{t_{c^2}} (psi)$$

$$\frac{1}{C_b} = 1.34 \times 10^{10} \frac{B\rho_b}{t_{c^2}} (psi)$$

Where:
G = Shear modulus (psi)
C_b = Bulk compressibility (psi^{-1})
ρ_b = Bulk density ($\frac{gm}{cm^3}$)
t_c = Compressional transit time ($\frac{\mu s}{ft}$)

The constants A and B are determined by Poisson's ratio (ν) using the subsequent formulas:

$$A = \frac{1-2v}{2(1-v)}$$

$$B = \frac{1+v}{3(1-v)}$$

Several proposals have been put forward to estimate Poisson's ratio from log data, but studies show that the ratio of shear modulus to bulk compressibility is not highly sensitive to this parameter (Bellarby, 2009; Nur, Byerlee, 1971). This observation highlights the multi-parametric and complex nature of sand control, emphasizing the necessity of considering various parameters and indicators for devising a comprehensive sand control strategy.

2.5.4 Well testing methods

Accurate identification of sustained sand production at initial reservoir pressures necessitates meticulous well tests conducted using both surface and downhole sand detection equipment (Bellarby, 2009). Notably, testing and completion equipment should be able to meet specified drawdowns and rates (Bellarby, 2009). Testing should persist even if initial sand production has ceased and be continued until the sand influx rate demonstrably diminishes, suggesting the cessation of further sand inflow (Bellarby, 2009). A comprehensive step-rate test involving multiple cycles and prolonged flow durations is recommended to ensure effective completion of the well and a proficient perforation and cleanup program (Bellarby, 2009).

The Step Rate Test or Injectivity Test, is a crucial aspect of sand control, particularly in injection wells. It enables the determination of a formation's injectivity profile and its responses to variable injection rates (Bellarby, 2009). The test's principal objective is to identify the ideal injection rate, ensuring neither sand production nor formation fracturing are induced (Bellarby, 2009).

The test entails gradually augmenting the injection rate in pre-defined steps, while continuously monitoring and recording the corresponding pressure responses in the well (Bellarby, 2009). Each step-rate is maintained until stable conditions are established, preceding the transition to the subsequent rate increment (Bellarby, 2009). The process allows the detection of formation parting pressure, a crucial pressure level, which, if exceeded, may induce formation fracturing (Bellarby, 2009). This condition typically manifests as a deviation from linearity on a pressure versus injection rate plot (Heriot Watt University, 2016).

Understanding this relationship is fundamental in sand control. Overly high injection rates can cause formation fracturing and, consequently, undesired sand production (Bellarby, 2009). Identifying the optimal injection rate via a step rate test enables operators to adjust their injection operations to preclude these complications, optimizing reservoir productivity and longevity, while reducing operational difficulties and costs (Heriot Watt University, 2016).

The Restricted Drawdown Test (RDT) is another vital tool in oil and gas operations, facilitating understanding and prediction of sand production by managing and controlling drawdown pressure within the well. The RDT, conducted on a select number of perforations, simulates stress conditions expected during reservoir pressure depletion. However, its reliability has been disputed due to challenges encountered during testing and the high flow rates it produces (Bellarby, 2009).

RDT can be highly advantageous in sand management and in curtailing unwanted sand inflow. The procedure involves a gradual increase in the flow rate or drawdown, monitored closely for signs of sand production (Speight, 2015). The critical drawdown, or the maximum drawdown without inducing sand production, is a crucial data point for operators.

This critical drawdown sets a limit for future drawdowns in production, ensuring that sand production remains within acceptable limits (Speight, 2015). The key principle is that lower drawdowns will reduce the shear stress on the formation face, consequently decreasing sand production.

However, the reliability and usefulness of the RDT depend on meticulous planning, execution, and interpretation of the test data (Bellarby, 2009). For successful implementation and interpretation of test outcomes, a comprehensive understanding of the reservoir's geomechanical properties is indispensable (Heriot-Watt University, 2016).

3. Necessity for Sand Management

The occurrence of sand production in oil fields can instigate a plethora of operational difficulties. These issues may range from challenges in sand handling and loss of profitable zones to the ominous risk of complete well failure. Effective sand management hence becomes a non-negotiable necessity to circumvent these potential problems. The acceptable rate of sand production varies among operators, intricately tied to reservoir conditions and the nuances of operational logistics. While onshore management of modest sand production rates might be straightforward, the offshore environment poses considerable challenges. Environmental concerns here necessitate that oil is meticulously separated from solid materials prior to disposal (Heriot Watt University, 2016).

Sand erosion is a pervasive problem in both downhole and surface equipment, especially prevalent when sand is produced concurrently with gas or when produced fluids are in transport. High-pressure gas laden with sand particles can severely erode downhole equipment and even infiltrate the surface choke, culminating in hazardous situations that could cause a total loss of effective well control (Ott & Woods, 2003).

Sand production management acquires paramount importance given the substantial risk of production loss stemming from various complications. These complications could include valve malfunctions in downhole rod pumps, issues with cutout valves in downhole rod pump plungers, or steady reservoir depletion (Acock & Shimboh, 2004).

NODAL analysis emerges as an invaluable tool in addressing these concerns. As a comprehensive system-level approach, NODAL analysis aims to optimize oil and gas well output by scrutinizing the overall system's performance (Brown, 1986). By examining the decline of pressure within the reservoir, it enables accurate forecasts of future production rates. A precipitous decline could act as a red flag, signaling potential complications that demand immediate intervention (Brown, 1986).

Tackling sand production issues might entail workovers, which could in turn necessitate temporary well shutdowns (Acock & Shimboh, 2004). Such measures, while necessary, could reverberate across the productivity of the individual well and potentially even the profitability of the entire field. This underlines the compelling need for robust sand management strategies (Acock & Shimboh, 2004).

Furthermore, in the sphere of well integrity, the risk of casing or liner collapse is significant, often instigated by pressure reduction and the production of solids from the surroundings of the wellbore (Matanovic, Cikes, & Moslavac, 2012). In poorly or unconsolidated formations, a decrease in formation pressure could lead to subsidence. The subsequent diminished ability of the reservoir rock matrix to bear overburden pressures could trigger the settling of subsurface structures (Matanovic, Cikes, & Moslavac, 2012). In scenarios where the casing has to be removed or abandoned, the ensuing additional load could pose further threats to the structure. However, controlling the volume of sand entering the wellbore can potentially mitigate such casing collapses, thus safeguarding the integrity of the well (Matanovic, Cikes, & Moslavac, 2012).

Figure 6: Issues caused by sand production (eProcess Technologies)

Sand production, if not properly managed, can pose significant challenges across various dimensions of well operation, ranging from technical to economic aspects (Bellarby, 2009; Veeken & Davies, 2000).

Unmonitored sand production may induce obstructions within the wellbore, inhibiting access to the completion interval and potentially creating cavities in its proximity (Bellarby, 2009). This can lead to zonal isolation impairment, increased operational complexities, and, in the case of heightened clay particles presence, a stark reduction in permeability (Bratli & Risnes, 1981). Furthermore, such disruptions can accelerate casing erosion and limit full-diameter access to the completion interval (Bellarby, 2009).

Well tubing can also be significantly impacted by excessive sand production. Sand bridges can form within the tubing, shrinking its effective diameter and triggering production declines or even reservoir loss (Bellarby, 2009). Subsurface apparatus, such as valves and casings, can become unfit for operation due to sand accumulation, necessitating replacements and augmenting operational burdens (Ghalambor, 2015).

Environmental concerns present another layer of complexity. Sand accumulation within separators and heat exchangers can degrade their capacity over time (Bugachev & El-Dabi, 2011). Erosion of equipment and pipelines may also occur, heightening the risk of oil or gas leakage, particularly at critical junctures like 90-degree pipe bends (Bugachev & El-Dabi, 2011). Hence, the potential environmental ramifications further emphasize the indispensable nature of robust sand control measures (Wang & Economides, 2009).

3.2 Strategies for Sand Management

Sand management approaches primarily focus on keeping load-bearing materials intact within their original reservoir structure. This is vital to reach the desirable outcomes of these interventions (Bellarby, 2009). The creation of fines, minuscule particles or fragments, might open up additional pore spaces, thereby potentially enhancing formation permeability (Tiffin, 2003).

Before the successful completion of a well, several integral operations, including drilling, casing cementing, perforating, and downhole tool installation, must be carried out (Bellarby, 2009). This sequential series of tasks prepares the well for optimal operation and eventual successful completion.

The preciseness of project completion forecasts hinges on numerous key variables. These encompass reservoir pressure and temperature, productivity index, sand production volume, water cuts, and possible formation damage (Bellarby, 2009). Additionally, the features of formation permeability and reservoir thickness demand careful analysis given their significant influence on project outcomes. Comprehensive examination and verification of every element are required to optimize the accuracy of resultant predictions (Bellarby, 2009). Therefore, implementing successful sand management strategies fundamentally depends on the detailed assessment and handling of these multifarious factors.

Various techniques are available within sand management to mitigate and regulate sand production. Sand production might pose an issue from the beginning or arise intermittently during the process. Several studies advocate proactive sand management techniques as the most efficient way to anticipate and control sand production. Typical sand control measures include:

1. Rate restrictions: This cost-effective method involves limiting production rates to prevent sand production. However, its effectiveness diminishes as reservoir conditions change over the well's lifetime.

2. Screens or prepacked liners: Mechanical control using slotted or wire-wrapped liners without gravel packing is often employed in thick, high-pressure, low-flow-rate periods, particularly in formations containing fine-grained particles.

3. Selective perforating: This approach involves identifying the most productive intervals in the pay zone using mechanical properties logs and only perforating those intervals. It serves as an interim measure for sand management. However, restricting production based on maximum flow rates may significantly impact recovery rates, and the long-term predictability of control is debated due to potential changes in formation characteristics over time.

4. Mechanical prestressing: This method involves applying mechanical prestressing techniques to the wellbore, such as casing deformation or swell packers, to improve sand control. It can be effective in certain conditions but requires careful design and implementation.

5. Resin-coated gravel pack: This technique involves placing resin-coated gravel packs around the wellbore to provide sand control. It offers good results in terms of sand exclusion but requires proper design and execution to ensure long-term effectiveness.

6. In-situ sand consolidation: This approach aims to consolidate the formation sand in-situ using chemical or thermal methods, thereby preventing sand production. It is often used in specific well conditions and requires careful consideration of the reservoir and formation properties.

7. Gravel packing: This method involves placing a gravel pack around the wellbore to support the formation and prevent sand production. It is commonly used in sand-prone formations and can be combined with other techniques for enhanced effectiveness.

The success of each method depends on its inclusion in the project plan from the beginning. It is important to note that when it comes to well sand treatments, the likelihood of successful treatment decreases significantly once the well has already started producing sand, as sand particles and formation fines become mobile around the wellbore (Bellarby, 2009).

Mechanical prestressing is anticipated to achieve the most successful outcomes in formations of short to medium thickness that have minimal concentrations of silt and clay. This technique is characterized by the injection of particles into the formation, which are used to pack it and generate stress, restoring the zone to its initial stress levels. While the wellbore can tolerate short-term plugging by clay and other migratory particles due to the expansion of a wide permeability zone around it, the long-term efficacy of this procedure might be constrained and achieving full zone coverage could pose a challenge. At present, the technique is primarily applied as a pre-treatment in combination with another sand control measure, ensuring comprehensive zone coverage (Bellarby, 2009).

The resin-coated gravel pack technique, implemented without the need for a screen, is notably beneficial in thinner formations characterized by a low content of clay and silt. This approach maintains a complete operational diameter for tools, a requirement met as the drilling of the wellbore occurs post-treatment. It holds particular utility in scenarios of multi-zone completions or when identification abilities are limited, such as in through-tubing completions (Schlumberger, 2010). On the other hand, in contexts of extensive zones or wells possessing a high count of perforations, the probability of achieving uniform distribution of all resin-coated particles across every perforation may decrease (Bellarby, 2009; Papamichos & Muecke, 1996).

In-situ consolidation techniques are advanced sand control strategies primarily employed to stabilize unconsolidated sandstone reservoirs and limit sand production. They typically involve the injection of chemicals or resins into the formation to enhance its mechanical strength and improve its resistance to sand mobilization. These injected substances work by binding the loose sand particles together, thus consolidating the formation and preventing the detachment and production of sand during the extraction process. Examples of in-situ consolidation techniques include resin injection and chemical consolidation treatments, each tailored to specific reservoir conditions and operational requirements (Saunders et al., 2004; Bellarby, 2009).

3.2.1 Gravel packing

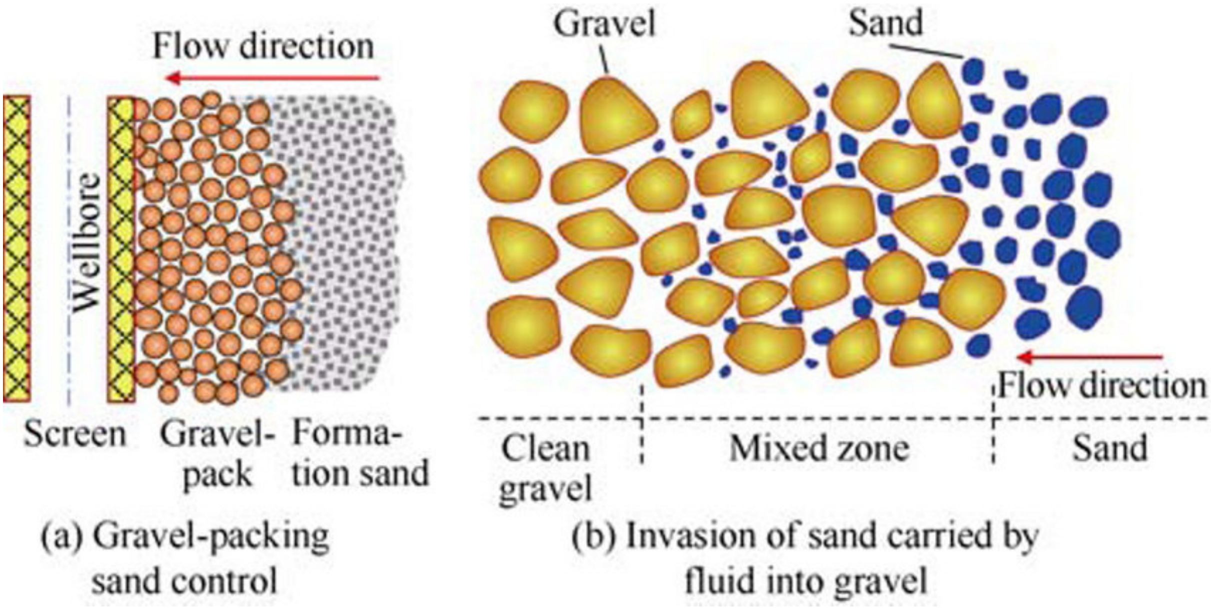


Figure 7: Illustration of sand control with gravel packing. Adapted from Dong et al., 2019.

Gravel packing serves as a reliable method for tackling sand production issues within oil and gas wells, using coarse, clean natural or synthetic sand (gravel) positioned in the annulus between the screen-casing or screen-open hole, effectively halting the movement of formation particles, fines, and rock grains (Bellarby, 2009; Bugachev & El-Dabi, 2011).

The gravel packing process involves injecting gravel slurries and a carrier fluid around the screen assembly. As the carrier fluid penetrates the formation or is recirculated to the surface through the wash pipe, it leaves behind a protective layer of gravel (Bellarby, 2009).

Due to its proven efficacy, gravel packing is not only used in vertical wells but has also been implemented in deviated and horizontal open-hole wells, providing cost-effective solutions, especially in depleted and unconsolidated reservoirs (Bellarby, 2009; Bugachev & El-Dabi, 2011).

The choice between the two major gravel packing types, open-hole gravel pack (OHGP), and cased-hole gravel pack, hinges on the screen's effectiveness in handling the formation sand particle size (Bugachev & El-Dabi, 2011). If the standalone performance of the screen falls short, an open-hole gravel pack completion could be considered. This approach, also known as gravel flooding, pumps gravel into the gap between the screen and the formation.

The initial steps in the completion sequence involve cementing the upper portion of the productive interval and drilling the borehole through the productive interval below the casing. Following these steps, the assembly is situated within the opening, guided by a sand control screen (Bugachev & El-Dabi, 2011).

The gravel packing process commences by pumping a mixture of a carrier fluid and high-quality coarse sand or gravel, chosen for its optimal size and high permeability, down the wellbore. This mixture fills the annulus between the formation and the screen, eliminating any voids (Heriot Watt University, 2016). After the assembly has been fully removed, production starts with the introduction of tubing, paving the way for the well's production process (Bellarby, 2009).

In this setup, the gravel acts as an efficient filter, blocking the movement of formation sand, while the screen keeps the gravel in place and hinders fluid intrusion. Correct selection of screen openings and the type and quantity of gravel used are critical for managing sand ingress into the wellbore, thereby ensuring a robust and lasting downhole completion, facilitating the production of well fluids free of formation particles (Bugachev & El-Dabi, 2011).

The cased-hole, or internal gravel pack, bears resemblance to the open-hole gravel pack, though it differs in key areas. The cased-hole technique employs a gravel pack inside a pre-perforated casing or liner, supporting multi-zone completions. The choice of perforation technique and gun system needs careful consideration to optimize performance while minimizing damage (Bugachev & El-Dabi, 2011).

Successful cased-hole gravel packing necessitates a uniform distribution of gravel within the perforations to ward off turbulence and erosion. The process can be broken down into three key stages: developing a viable packing strategy, choosing suitable sand and gravel, and identifying the appropriate fluid for the job, followed by efficient gravel placement (Bugachev & El-Dabi, 2011).

Each step requires in-depth evaluation to ensure well completion success. Nonetheless, both open-hole and cased-hole gravel packing face a common challenge: managing the skin factor, a term referring to the degree of flow restriction near the wellbore. High skin values can hinder overall production by decreasing the well's flow efficiency (Economides & Nolte, 2000). Figure 8 provides a comparative overview of the open-hole and cased-hole gravel pack methods, illustrating their respective merits and challenges (Bugachev & El-Dabi, 2011).

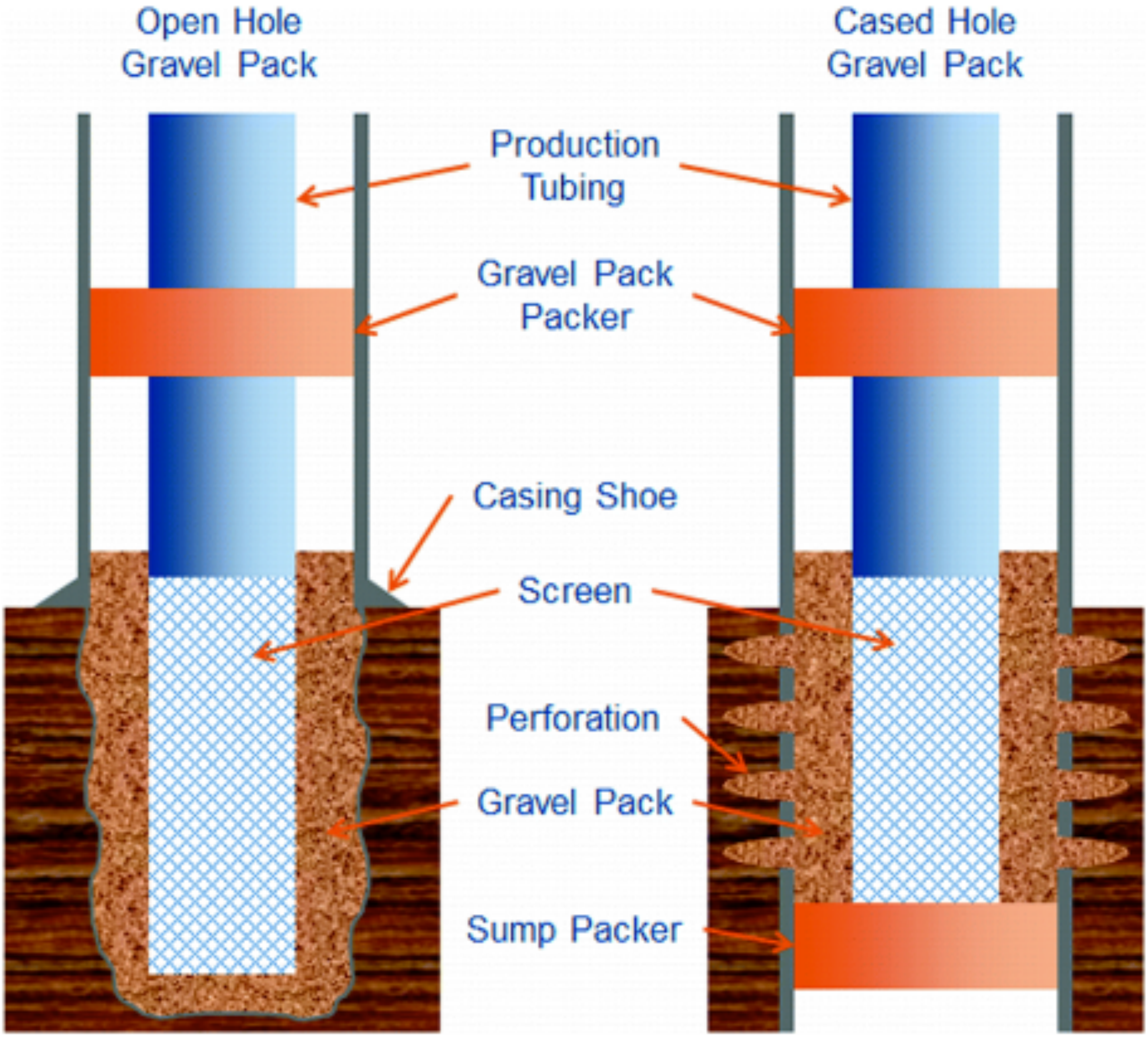


Figure 8: Open Hole- & Cased Hole Gravel Pack (Resources -DuneFront.com)

3.3 Sand Control Method Selection

In the process of selecting a suitable sand control method, various influential factors warrant careful consideration and evaluation. These include:

1. Reliability: Given that the failure of sand control can result in severe implications, especially in subsea wells or fields, historical data on reliability should be scrutinized. It is essential to make these comparisons under similar conditions and employ valid statistical techniques (Bellarby, 2009).

2. Productivity: The effect on reservoir completion productivity is another crucial consideration. Detailed production profiles that factor in elements such as upper completion effects, reservoir depletion, and water or gas influx should be utilized in this assessment (Bugachev & El-Dabi, 2011).

3. Cost: A comprehensive evaluation of the costs associated with sand control measures is also necessary. This should cover both direct costs such as equipment and installation, and indirect costs like prolonged drilling time and longer reservoir sections (Economides & Nolte, 2000).

4. Capacity to control water or gas: In certain cases, reservoir modeling might be required for an accurate evaluation of the benefits, and proactive control measures for water or gas might be necessary.

5. Fluid compatibility: During the preliminary design stages, it's important to consider the compatibility of sand control methods with the drilling mud in use. Exploring alternative solutions and conducting experiments with different mud types early on can be beneficial (Bellarby, 2009).

For optimal sand management within a specific well or field, it's critical to thoroughly evaluate the relevant criteria and determine the most fitting sand control strategy (Bugachev & El-Dabi, 2011).

Validating the reliability and productivity of the chosen method often necessitates tangible evidence, typically obtained through empirical testing whenever feasible (Bugachev & El-Dabi, 2011). Useful testing methods encompass:

- Examining the potential for clogging and erosion of standalone and expandable screens through exposure to a mixed slurry (Bellarby, 2009).
- Assessing the risk of fines invasion by conducting gravel packing tests with a core made of casting material (Bellarby, 2009).
- Comparing compliant and non-compliant techniques under increased stress conditions to observe changes in fines production and permeability (Acock & Shimboh, 2004).
- Studying the size of sand particles, which, although not directly testing sand exclusion methods, provides valuable comparative data and aids in high-level screening between fields (Bellarby, 2009).

These evaluation methods are invaluable in the process of selecting and implementing the most effective sand control strategy (Bugachev & El-Dabi, 2011).

The importance of a robust sand control strategy cannot be overstated in the initial stages of well planning, especially when sand production is anticipated (Bellarby, 2009). Typically, sand control strategies aim to create a filter around the wellbore, designed to restrict sand movement while allowing fluid passage (Bugachev & El-Dabi, 2011).

The size of the gravel particles selected for the filter should be determined carefully based on the size of the sand particles targeted for control (Heriot Watt University, 2016). It is crucial to avoid overly small particles, which could increase the differential pressure and consequently affect productivity. Conversely, overly large particles could potentially lead to control loss and are thus unsuitable (Acock & Shimboh, 2004).

Modifying the filter collar's diameter at the surface while maintaining the same permeability can help reduce differential pressure without compromising productivity or control (Zhou & Sun, 2016). In certain situations, open-hole completions may be considered to avoid the need for a filter with a larger external diameter (Ott & Woods, 2003).

In environments where high pressure is a challenge to the filtration system, potential solutions could include using a larger casing or employing in-situ sand consolidation methods to enhance flow capacity (SLB internal materials).

Upon identifying and evaluating various sand control strategies, it is recommended to carry out a comparative risk and economic assessment. This systematic approach can facilitate informed decision-making and lead to the selection of the most appropriate techniques (Bellarby, 2009).

3.4 Mechanical screens

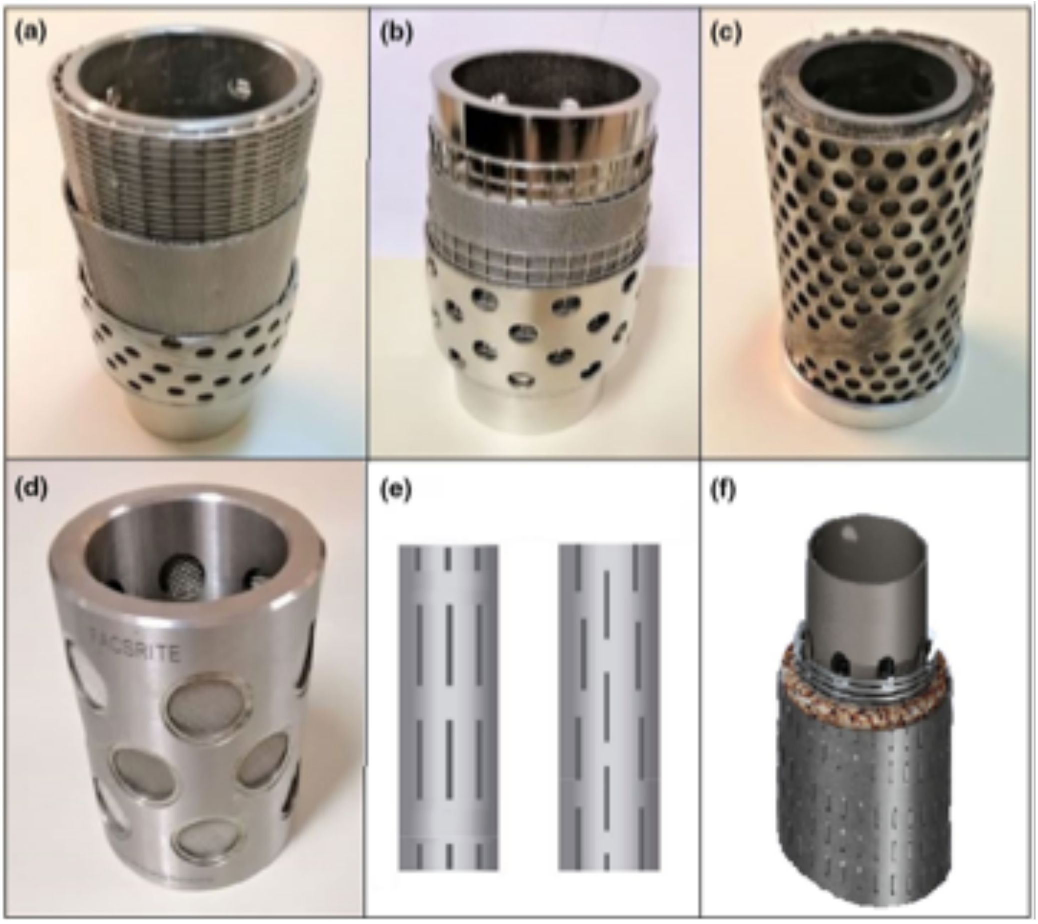


Figure 9: Varieties of stand-alone screens: (a-b) multi-layered premium screens; (c) wire-wrapped screen; (d) basic screen; (e) slotted liner; (f) prepacked screen. Photographs (a-d) were taken and images (e-f) were created by Jami Morteza.

Mechanical sand control employs various techniques including the use of slotted liners, wire-wrapped screens, direct-wrap wire wrap screens, pre-packed screens, premium screens, and expandable screens, or a combination of these with gravel packs, to contain sand within the formation (Bellarby, 2009). Key design elements that warrant careful consideration include:

1. The Determining the most suitable slot width for the mechanical screen, considering both scenarios with and without gravel (Bugachev & El-Dabi, 2011).

2. Specifying the optimal size and distribution of gravel, essential for ensuring effective sand control (Heriot Watt University, 2016).

3. Developing an effective strategy for the placement of these screens, tailored to the unique conditions of each well (Ott & Woods, 2003).

3.4.1 Slotted liner

Figure 10: Slotted liner (Drilling Formulas 2016)

The slotted liner, also known as a slotted pipe, is fundamentally a steel tube or casing equipped with axial slots (Bellarby, 2009). This component plays a crucial role in providing mechanical reinforcement to the wellbore, preventing its collapse under stress. Slotted liners are primarily used when horizontal wells intersect unconsolidated, high-permeability sands that produce high-viscosity oil (Acock & Shimboh, 2004).

For achieving optimal performance, the formation needs to have well-sorted sand grains and proper cementation (Zhou & Sun, 2016). In situations where the formation lacks appropriate sorting, and the produced sand contains diverse grain sizes and impurities, the liner may become clogged with sand. This issue can reduce the productive lifespan of the completion (Heriot Watt University, 2016).

Small formation grains pose a particular challenge in lengthy horizontal sections, as they can't be effectively transported to the surface at low inflow rates (SLB internal materials). Due to their cost-effectiveness, slotted liners have become a common choice in sand control systems for such wells (Ott & Woods, 2003).

Slotted liners perform a dual function: they provide structural support and serve as a containment medium for gravel. In situations where sand control relies on bridging, a secondary sand filtration zone may be installed (Bellarby, 2009). The primary reason for integrating gravel-packed liners is to enhance the efficiency of sand management (Heriot Watt University, 2016). To ensure maximum retention of formation sand, the slots in the liners should be minimized to the smallest feasible size. While this approach is both straightforward and cost-effective, it can lead to a reduction in flow in cased-hole completion when the slots become blocked, necessitating the deployment of a liner or screen without a gravel pack (Ott & Woods, 2003).

3.4.2 Wire-wrapped screens

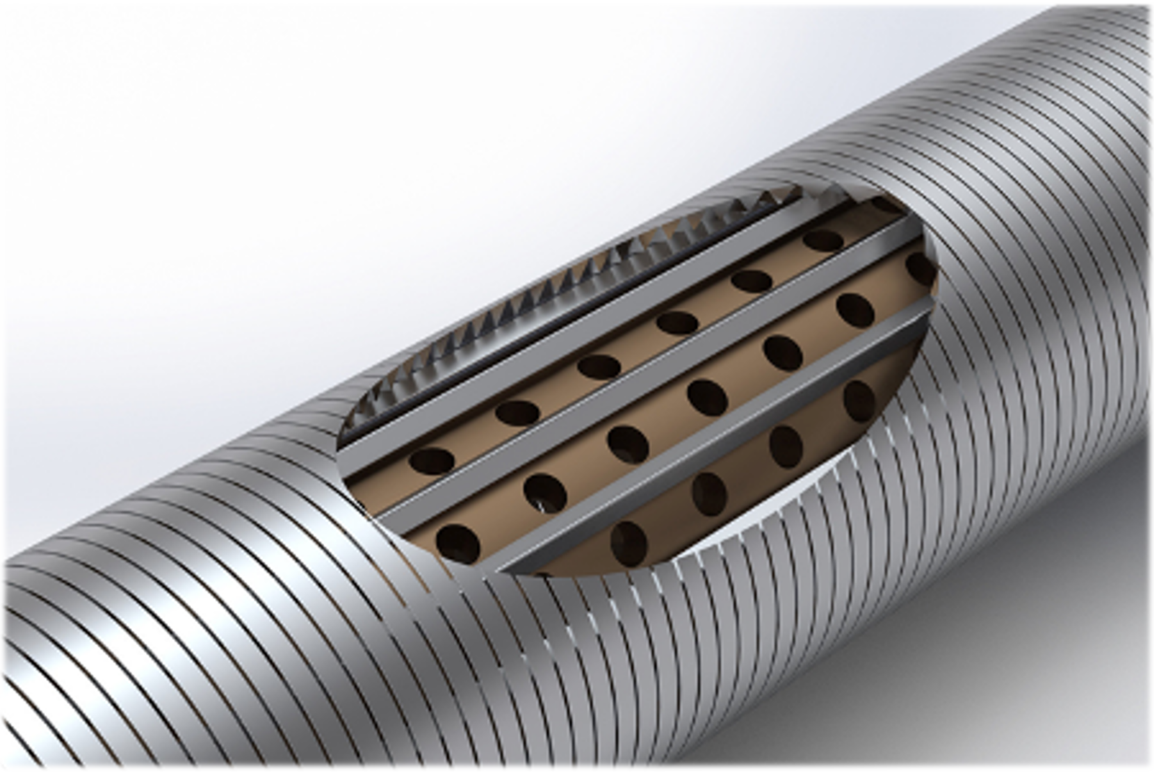


Figure 11: Wire wrapped screen (Completion Products)

Wire-wrapped screens, essential for sand control, are fabricated using specific wrapping machines (Bugachev & El-Dabi, 2011). The construction of these screens involves wrapping triangular-shaped wires around longitudinal support rods, maintaining a consistent gap between each wrap (Acock & Shimboh, 2004). The precision and narrowness of wire spacing are vital to ensure a stable, slot-like opening between wraps.

This technique results in a wire-wrap filter, characterized by curved wires helically wound around longitudinally oriented rods. The unique construction creates a distinct, uniform gap between consecutive wraps. This gap serves as a "filtered" channel, enabling the efficient passage of effluents while inhibiting the entry of solid particles (Acock & Shimboh, 2004).

The sizing of the gap between measurement ports, specified in gauges, is intended to prevent solid particulates from contaminating the flow stream. The standard wrap wire width typically measures 0.090 inches. Wire widths falling within the range of 0.090 to 0.100 inches are designated as high flow wire wrap screens. Any wrap wire height exceeding 0.088 inches is categorized as a heavy-duty wire wrap screen, suited for more demanding conditions (Zhou & Sun, 2016).

Wire-wrapped screens are preferred for sand control in oil and gas extraction, particularly when dealing with fine-grained geological formations, wire-wrapped screens enhance well productivity by optimizing the flow area (Bugachev & El-Dabi, 2011). They trap formation sand while facilitating fluid inflow into the well, outperforming alternatives such as slotted liners (Zhou & Sun, 2016).

Wire-wrapped screens offer adaptability, making them suitable for diverse well specifications. Customization allows them to have varying slot sizes that match the formation grain size, thereby increasing their efficiency in sand control (Bellarby, 2009).

Performance augmentation is also possible when wire-wrapped screens are paired with gravel packs. The wire wrapping contains the gravel pack, and allows fine particles to either be trapped or pass through the slots based on their size, enhancing well stability and longevity (Acock & Shimboh, 2004).

An innovative subtype of wire-wrapped screens is the Hi-Flow screen, characterized by a wrap wire width of less than 0.090 inches, promoting superior fluid flow due to a larger open area in the screen jacket. The base pipe in Hi-Flow screens is specifically designed with a 10% open area to maximize this benefit. When combined with a slip connection, the Hi-Flow screen's design proves promising for efficient and effective sand control management (Zhou & Sun, 2016).

3.4.3 Direct-Wrap Wire Wrap Screen

Figure 12: Direct wire Wrapped Screen (SLB)

The Direct-Wrap Wire Wrap Screen is a uniquely constructed device, with wires wound directly around the base pipe and ribs, resulting in a notably compact product (SLB internal materials). This manufacturing approach occasionally obviates the need for welding to the base pipe, offering certain operational advantages (Zhou & Sun, 2016).

This screen design includes a perforated base pipe that lends support to the rib wires of the Direct-Wrap Screen (Ott & Woods, 2003). Such a configuration enhances the collapse resistance in comparison to an equally perforated base pipe without rib wires (Acock & Shimboh, 2004).

However, a distinctive characteristic of the Direct-Wrap Screen's fabrication process is the requirement for thicker wrap wire. This necessity lends itself to a more robust screen structure, potentially prolonging the screen's operational lifespan and enhancing its performance under challenging conditions (Bellarby, 2009; Zhou & Sun, 2016).

3.4.4 Pre-packed screens

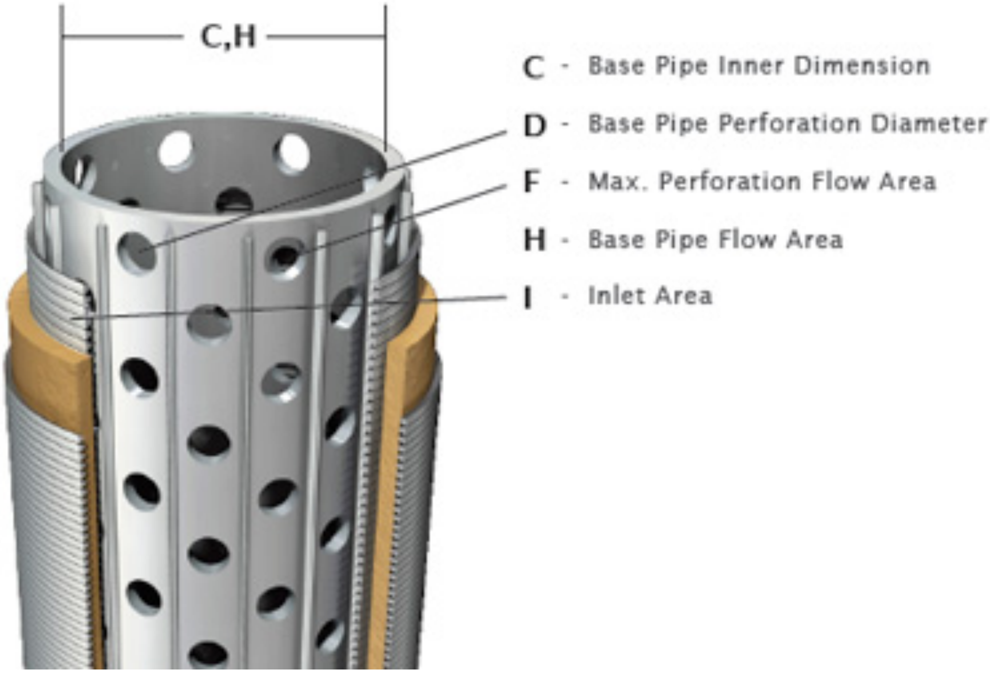


Figure 13: Pre-Packed Screen (Delta Screens)

Pre-packed screens represent an evolution of the standard wire wrap screens. They consist of two concentric wire-wrapped screens that encase a layer of resin-coated gravel (SLB internal materials). Their standout feature is the ability to maintain the annular space between the sand screen and formation sand-free. This inherent attribute aids in the prevention of sand failure and transport, thereby optimizing well stability and performance (Ott & Woods, 2003; Zhou & Sun, 2016).

Unlike traditional screens, pre-packed screens remain stable, not subject to expansion or contraction. Nevertheless, they do exhibit some filtration and minimal resistance due to their high porosity and permeability (Bellarby, 2009; Heriot Watt University, 2016). The thickness of the gravel layer can be adjusted to meet specific requirements. The packed screens undergo heating in a specialized oven to cure and harden the resin, enhancing consolidation and permeability and reinforcing the formation's robustness (Acock & Shimboh, 2004).

The screen slots are meticulously designed to prevent the gravel from escaping between the screens (SLB internal materials). The dual wire-wrapped screen is supported by a perforated pipe, resulting in a smaller pore throat diameter because of the resin-coated gravel and a reduced flow area (3-6%) (Heriot Watt University, 2016; Zhou & Sun, 2016).

Despite the utility of pre-packed screens in scenarios where gravel packing is not feasible, contemporary installations have largely favored premium screens and simpler wire wrap screens. However, they continue to find use in certain high-demand situations (Bellarby, 2009; Acock & Shimboh, 2004).

3.4.5 Premium screen

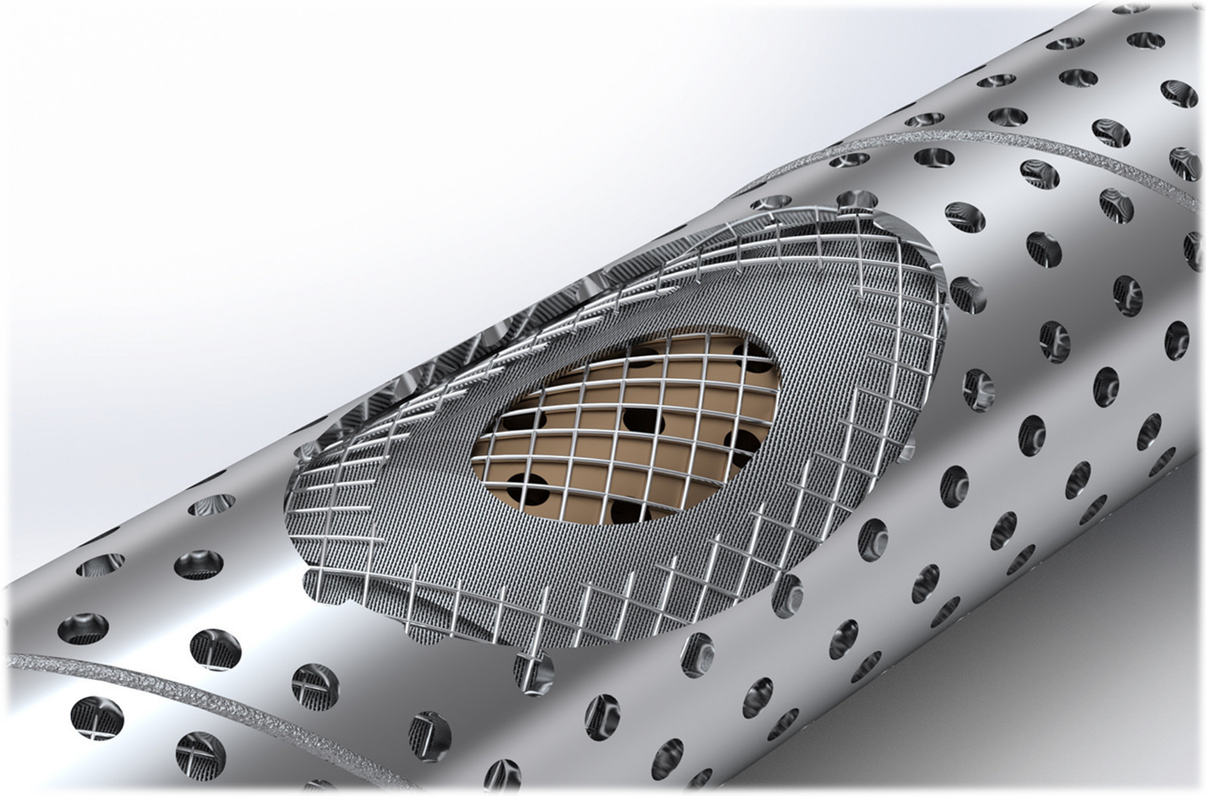


Figure 14: Premium Screen (Completion Products)

A premium screen, a filter uniquely constructed with several layers of woven wire mesh, distinguishes itself through robust design and performance. The initial two layers add mechanical strength, while the outer layer provides protection during manufacturing (SLB internal materials; Bugachev & El-Dabi, 2011). Sintering these layers forms a solid mesh tube, a process that mitigates changes in pore openings from mechanical stress (Zhou & Sun, 2016).

A prominent feature of a premium screen is the complex open area of the sintered laminate, which allows efficient filtration of even non-uniform sands. The screen's design also affords superior erosion resistance due to its larger openings (Ott & Woods, 2003; Heriot Watt University, 2016).

Premium screen assemblies incorporate a perforated base pipe that permits 10% of the pipe open to effluents (Bellarby, 2009; Acock & Shimboh, 2004). The inner drainage layer, comprised of a stainless steel square or helically wound coarse mesh, acts as a standoff from the base pipe and provides an axial flow path for well effluents (Bellarby, 2009; Zhou & Sun, 2016).

Perforated shrouds encircle the external diameter of the filter medium, serving a dual purpose: protecting the mesh from damage and providing a maximum burst rating (SLB internal materials; Bugachev & El-Dabi, 2011). Additionally, the shroud supports the potential inclusion of a secondary drainage layer, or the outer drainage layer. This feature maintains a gap between the filter medium and the shroud, keeping the mesh surface more exposed to erosion and thereby increasing its erosion resistance (Bellarby, 2009; Acock & Shimboh, 2004).

The safety edge, a distinctive termination style for the sintered filter cartridge mediums, ensures a secure edge for welding the filter cartridge to the end ring. This design strategy helps to protect the mesh from potential damage during the welding process and subsequent heat treatment (Bellarby, 2009; Zhou & Sun, 2016).

3.4.6 Expandable screen

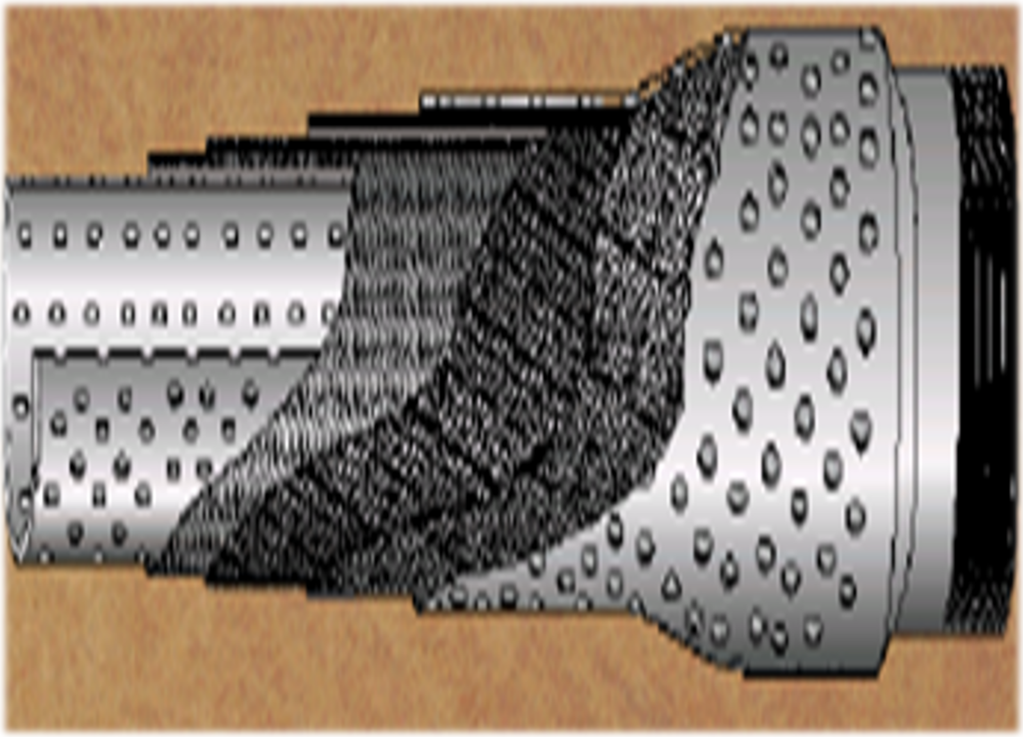


Figure 15: Expandable Screen (PetroBlogWeb 2016)

Expandable screens, a modern alternative to traditional sand control equipment, offer considerable cost and time efficiencies, particularly in circumstances that would otherwise require gravel packing (SLB internal materials; Bugachev & El-Dabi, 2011). This innovative variant of sand control consists of an expandable slotted tubular made from stainless steel, distinguished by its unique slot design (Bellarby, 2009; Zhou & Sun, 2016).

By deploying expandable screens, the need for an annulus is eliminated, providing more space for downhole tool operation and borehole support. This method also eradicates the necessity for gravel packing and streamlines sand exclusion (Ott & Woods, 2003; Acock & Shimboh, 2004).

An expandable screen consists of three primary components: an expandable slotted base pipe, a specialized woven mesh filter screen, and an external protective layer. The filter screen is engineered to accommodate the base pipe's expansion (SLB internal materials; Heriot Watt University, 2016).

This sand control method is beneficial for unstable formations, enhancing their resilience to high depletions. Despite its many advantages, it is not recommended for gas production (Bellarby, 2009; Zhou & Sun, 2016).

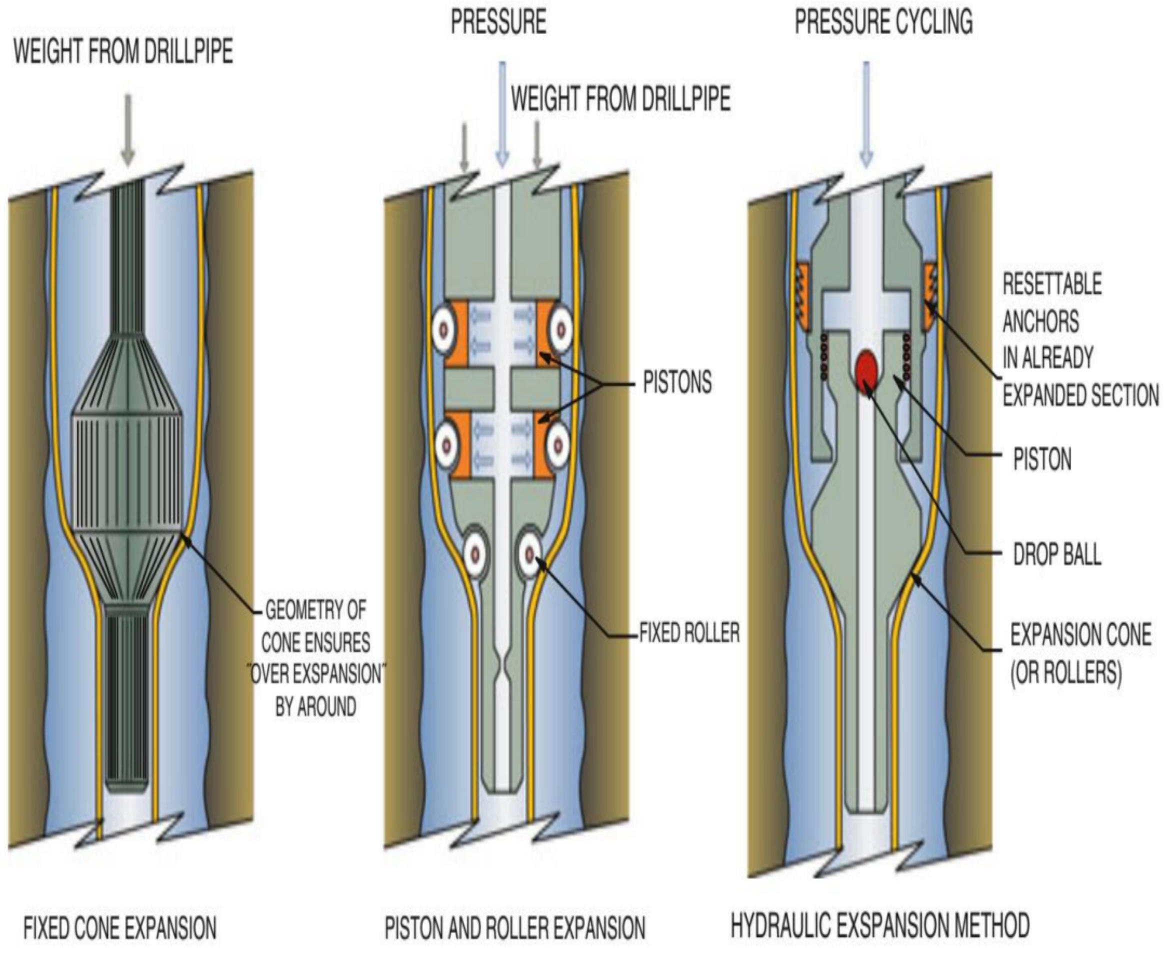


Figure 16: Expandable Screen Illustration (Bellarby, 2009)

The expansion of the screen involves moving an expansion mechanism through the string, accomplished by three primary techniques: fixed diameter cone expansion, fixed rotary expansion using rollers, and hydraulic expansion (Bugachev & El-Dabi, 2011; SLB internal materials).

In fixed diameter cone expansion, a conical wedge is driven down the string, resulting in the screen's contact with the wellbore wall. The screen is typically expanded slightly (2-3%) beyond the wedge's diameter to ensure a safe expansion pathway (Bellarby, 2009; Ott & Woods, 2003).

During fixed rotary expansion, pressure application on the pistons triggers the rollers' expansion, rapidly enlarging the screen. Hydraulic expansion is used when a significant force is needed for screen expansion (Bugachev & El-Dabi, 2011; Zhou & Sun, 2016).

The assembly's components include an expansion cone, piston, anchors, and a ball seat-fitted valve. Anchors stabilize the extended screen section, and a ball settles on the valve seat. Influenced by surface pressure, the piston pushes the cone downwards. While effective, this expansion method progresses slower than the fixed rotary expansion (Bellarby, 2009; Acock & Shimboh, 2004).

Using these methods, expandable joints can be enlarged up to 80-100% of their initial diameter (Bugachev & El-Dabi, 2011; Heriot Watt University, 2016).

3.4.7 Sand screen comparison

In conclusion, Section 3.4 presents a detailed examination of various sand control techniques, providing decision-makers with the essential knowledge to select the most appropriate equipment based on specific oil well needs, geological conditions, and budgetary limitations. The choice should take into account the balance between sand control effectiveness, cost, durability, and the ease of installation and maintenance. Following this paragraph, a comprehensive table comparing different types of sand screens will be presented for further clarity and understanding.

Equipment	Slotted liner	Pre Packed screen	Wire Wrapped screen	Expandable screen
Advantages	-Economical -Simplicity -High flow capacity -Low maintenance	- High filtration efficiency - Greater Stability of the formation and wellbore - Resistant to plugging	- High filtration efficiency -Economical -Durable -Higher flowrate	-Elimination of annulus -Sand exclusion without gravel packing -Wellbore stability
Disadvantages	-Slot Plugging -Erosion -Lack of Flexibility -Limited Sand Control	-Higher cost - Limited Expandability - Decreased flow area	-wire-wrapped screens can become plugged -Erosion -Limited strength -Not self-cleaning properties	-Limited applicability -Installation complexity -Risk of failure during expansion -Cost
Implementation	-Slotted liners are usually used in heavy oil reservoirs where sand production is less of an issue.	-Pre-packed screens are typically used when it's not feasible or practical to place a gravel pack	-Wire-wrapped screens are commonly used in wells where the formation consists of small grains that are not sticky, and the well productivity is not high	-Expandable screens are particularly useful in horizontal and vertical wells with weak formations where you need to manage sand production while also stabilizing the wellbore.

Table 1. 1: Comparison of Sand Screens

4. Understanding Mechanical Failures

4.1 Mechanisms of Failure in Slotted Liners and Wire-Wrap Screens

An engineering education sheds light on the forces acting upon various systems and materials, including corrosion, erosion, fatigue, and overload. It is possible to mitigate these adverse forces through effective design, assembly, and maintenance. For instance, the impacts of corrosion can be avoided, erosion can be shielded, vibration and movement can be restrained to prevent fatigue, and components and seals can be diligently maintained. The majority of these failure mechanisms can be mitigated by adhering to best practices. Additionally, it is crucial to maintain these preventive measures to minimize the risk of increased maintenance costs and elevated likelihood of failure. Grouping similar failure mechanisms aids in better understanding and application of preventative strategies.

4.2 Unmanageable Levels of Sand Production

Sand production is a multifaceted issue that emerges when fluid flow-induced forces, such as hydrodynamic drag, overpower the stabilizing forces that arise from inter-granular friction and cohesive bonds formed by cementing materials like clays. This imbalance can lead to five recognized circumstances of sand production in a wellbore (SPE, 1991):

1. Existence of unconsolidated or uncemented sands.
2. Emergence of weakly or intermediately consolidated sands post water breakthrough.
3. Abnormally intense and anisotropic lateral tectonic forces acting on strongly consolidated formations.
4. Depletion of reservoir pressure in moderately to strongly consolidated formations.
5. Abrupt changes in flow rate or excessively high production rates.

Two key mechanisms underpin sand failure in these situations. Firstly, shear failure arises from excessive shear stress near the wellbore. Secondly, tensile failure occurs due to drag forces acting on sand grains, a result of pressure differences induced by fluid flow (Morita et al., 1989). Issues become exacerbated as reservoir pressure depletion can heighten shear stress, while fine particle migration can block fluid flow channels, resulting in increased pressure drawdown and augmented sand production due to tensile failure (U.S. Rock Mechanics/Geomechanics Symposium, 1991).

Additionally, fluctuating production rates can provoke cyclic stress, thereby leading to rock fatigue. This decrease in rock strength can instigate sand production through both shear and tensile failure mechanisms (Morita et al., 1989). Sand production in problematic wells can be broadly grouped into three qualitative types:

1. Transient sand production, referring to a brief, intense sanding episode induced by abrupt operational changes such as perforation, acid clean up, or sudden shifts in production rates.
2. Continuous sand production, implying a steady sanding level associated with specific well operating conditions.
3. Catastrophic sanding, typified by rapidly escalating sand production levels, a sharp decline in fluid production, and eventually well failure. A particularly abrupt increase in production rate can trigger catastrophic sanding (SPE, 1991).

4.3 Screen Plugging

Drawing from various case studies, standalone screen failures are frequently traced back to screen erosion, an issue that can be intensified by screen plugging. A case in point is the Alba field in the North Sea where, despite a considerable amount of learning and adaptation, the wells averaged a disappointing 1.3 years before failure (Murray et al., 2001). Due to these repeated failures, the operator, Chevron, eventually shifted to gravel packing. Initial failures were predominantly due to mud plugging— a problem resulting from oil-based mud being displaced by a completion brine after the screen installation. Yet, even after substituting mud with sized salt and the introduction of premium screens, failures persisted. This prompted Chevron to conclude that the compatibility between the reservoir and the chosen completion method was suboptimal, largely due to the existence of reactive shales that induced screen plugging and led to the formation of erosion-prone hotspots, despite a uniform particle size distribution. This issue is inherent to standalone screens but can be alleviated by the use of expandable screens and gravel packs, which prevent open annulus formation and consequent shale smearing (Murray et al., 2001).

4.4 Influence of Fluid Flow Rate on Sand Control Measures

Research has underscored the critical role of fluid dynamics in the performance of Sand Control Devices (SCDs). Notably, excessive flow rates can trigger sand production and decrease productivity (Dolson, Muller, Evetts, & Stein, 1991; Wang, Pallares, Haftani, & Nouri, 2021). As such, the projected well production rates should be factored into the selection process of SCDs. Various factors, such as wellbore angle, shot density, and flow rate, alongside a shift in perforation patterns from spiral to in-plane and then inline, can significantly heighten sand production (SPE, 2000).

In circumstances where high fluid velocities occur near the wellbore, low-pressure zones may develop, leading to substantial pressure drops and an increase in drag on sand grains, thereby boosting the likelihood of sand production. The term "critical sanding rate" pertains to the flow rate that triggers sanding in a given well.

A study conducted by Dong et al. (2019) discovered that the depth and permeability of the sand-gravel mixed zone, in addition to the final permeability after gravel plugging, are inversely proportional to the flow rate and viscosity of the sand-carrying fluid. This suggests that an increase in the fluid's flow rate and viscosity would result in a reduction in the mixed zone's permeability, the final gravel plugging permeability, and mixed zone depth. Therefore, the fluid's flow rate and viscosity were identified as two crucial parameters that influence the degree of gravel plugging.

4.5 Sand properties

Particle size distribution (PSD) is a common method used for determining sand grain sizes, providing a thorough breakdown of grain sizes within a sand sample. Various laboratory techniques, including sieve analysis, Laser Particle Size Analysis (LPSA), and hydrometer analysis, can be used to obtain the PSD. Alternatively, well logging data can be utilized to infer grain sizes within geological formations by associating permeability, derived from logs, with the standard deviation of sand size and the mean grain size (Coberly & Wagner, 1938; Zhou & Sun, 2016). Nonetheless, since these techniques each have unique assumptions and respond differently to sand grains' distinctive, non-spherical characteristics, their results may exhibit discrepancies.

In sand control management, PSD is indispensable. It assists in the selection of suitable sand control methods and influences the design of opening sizes in Sand Control Devices (SCDs). Coberly (1938) suggested that when the aperture of an SCD is smaller than D10 (a size measurement indicating that 10% of grains are smaller than a specific size), stable sand bridges consistently form. In contrast, when the aperture exceeds 2xD10, stable sand bridges are unlikely to form, thereby defining an upper limit for sizing (Ott & Woods, 2003).

The methodology proposed by Constien and Skidmore (2006) underscores the significance of both the shape and distribution of the PSD. They introduced the Uniformity Coefficient (UC) along with D50 to assist in the construction of master curves used in sizing. Although modern design criteria consider factors like plugging tendency and stress, the role of PSD in SCD sizing is undeniable. Therefore, precise characterization of PSD remains vital for effective sand control management (Constien & Skidmore, 2006; Heriot Watt University, 2016).

Sand grain shape is affected by several factors, including the distance of sediment transport, mineral composition, and post-sedimentation chemical and mechanical processes (Resentini, Andò, & Garzanti, 2018). Traditional assessments of shape factors like roundness and sphericity were subjective and primarily based on visual analysis. However, recent advancements in image analysis have paved the way for mathematical definitions of sand grain shape, enabling quantification of factors such as sphericity, aspect ratio, and convexity.

Sand grain shape can influence a rock's hydraulic and mechanical behavior, which may in turn impact sand production. For example, Lu et al. (2019) employed fractal techniques to analyze grain shape, determining that sands with higher convexity exhibited a higher frictional angle. Similarly, Li and Iskander (2021) found that grain roundness affects the range of porosity and the friction angle of a sand pack. Han, Zhang, and Zhou (2019) used triaxial compression tests to show that as grain angularity increases and initial porosity decreases, the interlocking effect of grains enhances the friction angle of a specimen.

4.6 Influence of Salinity and pH Levels

Redekop et al. (2021) conducted research into the influence of salinity on rock fortitude, concluding that rocks immersed in a high-salinity brine solution exhibited superior resilience compared to those saturated with low-salinity brine. In contrast, a study by Ma et al. (2020) presented differing results, asserting that the rate of sand production remained largely stable, regardless of fluctuations in pH and salinity, in environments featuring unconsolidated sand - a condition that echoes the characteristics of Steam-Assisted Gravity Drainage (SAGD) wells. SAGD wells, utilized prominently in the extraction of heavy oil and bitumen, function on the principle of injecting steam into the oil reservoir to heat and dilute the heavy oil, which is then drained through a lower horizontal well. This process typically occurs in unconsolidated sandy formations, similar to the environment examined by Ma et al. in their study.

Several lab studies demonstrated a correlation between increased fines migration and reduced permeability, especially when salinity decreases and pH levels of the injected brine rise (Song & Kovscek, 2016). Khilar and Fogler (1984) introduced the concept of a critical salt content (CSC), a threshold below which fines release and migration commence. They further observed that the migration of fines is more influenced by the concentration of monovalent cations than bivalent ones.

Mishra et al. (2005) embarked on a study aimed at understanding the physicochemical elements that govern the stability and movement of clay particles within the porous medium of sandstone. Their findings highlighted the zeta potential and the properties of the electrical double layer as crucial determinants of clay mineral behavior. They also observed that the degree to which permeability was reduced varied with different salt concentrations, with Montmorillonite being the most impactful, followed by Kaolinite and Illite.

Various studies (Mahmoudi, Fattahpour, Nouri, & Leitch, 2016; Mishra et al., 2005; Khilar & Fogler, 1984; Song & Kovscek, 2016) have drawn attention to the reciprocal relationship between changes in salinity and pH levels. These studies underscore the importance of managing these variables in tandem to maintain the integrity of the formation. They further identified that the pH level of the brine injected into the formation can significantly influence the permeability of the porous medium, with higher pH levels generally leading to a decrease in permeability.

5.0 Approaches to Assess Sand Screen Performance

5.1 Introduction

The accurate evaluation of sand screens is critical to maintaining the integrity of oil wells, managing sand production, and ultimately ensuring a productive and economical extraction process. This section explores two primary techniques for assessing sand screens: slurry testing and sand pack testing.

5.2 Slurry Testing

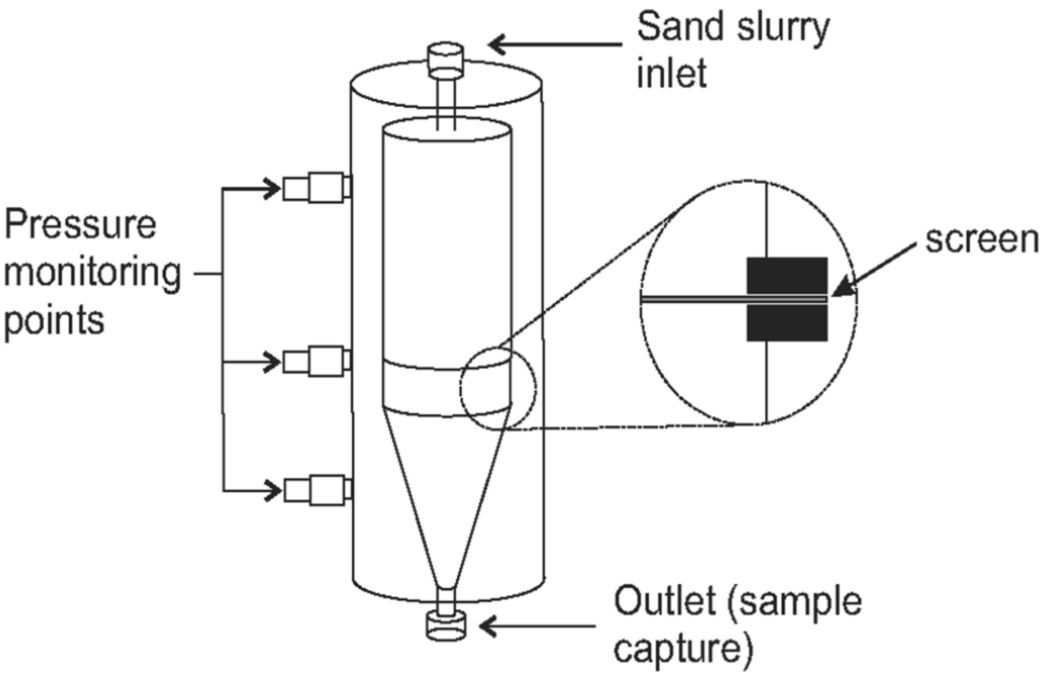


Figure 17: Illustrative diagrams of the slurry test setup, adapted from Agunloye and Utunedi (2014)

Slurry tests, also known as erosion tests, serve as a critical step in determining a sand screen's suitability and durability in oil well operations (Patel et al., 1996). These tests offer valuable insights into how the screen might perform under the harsh and complex conditions that characterize oil wells.

The test begins by preparing a slurry, which is a fluid mixture containing sand, water, and sometimes oil. The proportions of these ingredients in the slurry are designed to replicate as closely as possible the specific conditions the sand screen will encounter in the well, such as the sand type, particle size distribution, and fluid velocity (Peden et al., 1991).

Once the slurry is ready, it's pumped through the sand screen. This process simulates the conditions that the screen will experience in the well when oil and formation fluids are being produced, and sand particles try to migrate into the wellbore.

During the test, the screen's performance is evaluated in two primary ways. Firstly, the degree to which the screen erodes over time under the abrasive forces of the slurry is monitored. The erosion rate gives an indication of the screen's durability and potential lifespan. The lower the erosion rate, the more durable the screen is considered to be.

Secondly, the test measures the number of sand particles that pass through the screen while the slurry is being pumped. This measure gives an indication of the screen's ability to restrict the movement of sand under the test conditions. A screen that allows fewer particles to pass through will be more effective at sand control (Patel et al., 1996).

This two-fold assessment—checking both the erosion rate and the ability to restrict sand movement—provides a comprehensive understanding of the screen's potential performance in the field. This helps in making informed decisions about which screen type and design to use for a particular well. The slurry test, therefore, forms a crucial part of the sand control strategy.

It's important to note, however, that while slurry tests provide valuable data, they still represent laboratory conditions and therefore might not perfectly replicate all the challenges a screen might encounter in an actual oil well. Nonetheless, these tests are instrumental in the initial selection and design of sand screens.

5.3 Sand Pack Testing

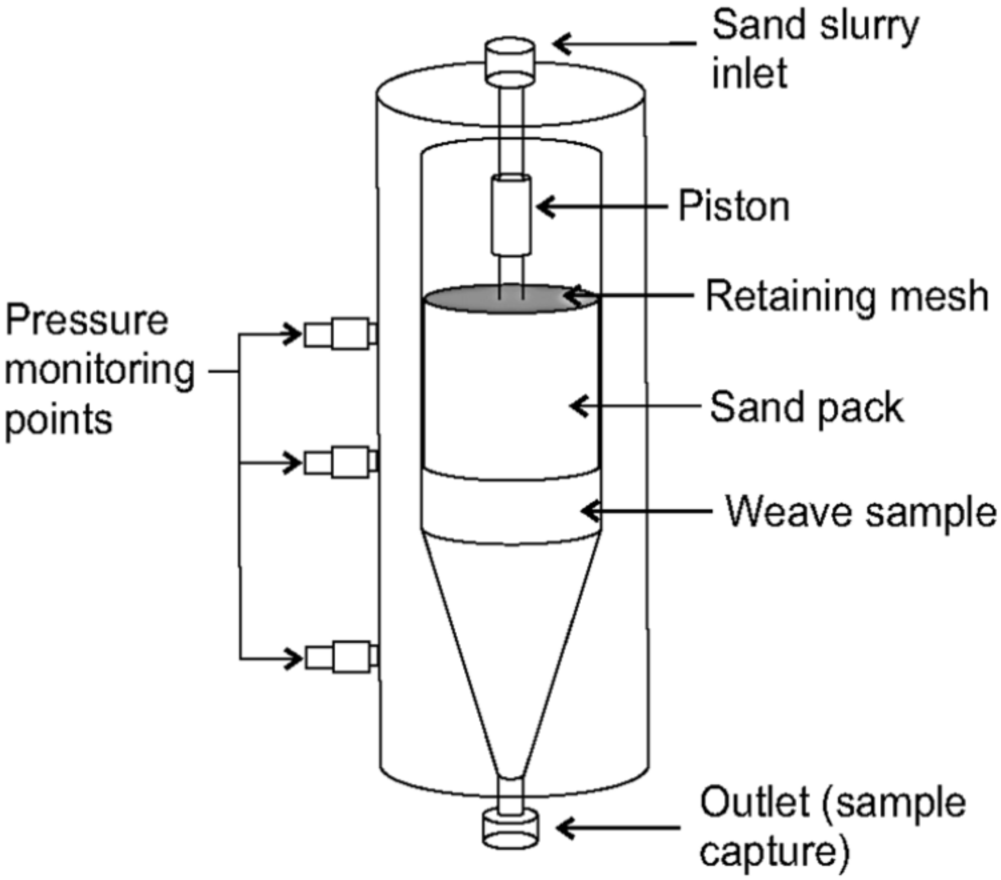


Figure 18: Illustrative diagrams of the sand-pack test setup, adapted from Agunloye and Utunedi (2014)

Sand pack tests are crucial tools for understanding the interaction between sand screens and the geological formations they are installed in. These tests simulate the static conditions surrounding the wellbore and are primarily designed to evaluate the screen's plugging resistance and its ability to control sand (Vaziri & Nasr-El-Din, 2005).

In a typical sand pack test, a sand screen is embedded within a carefully prepared assembly of sand particles, which is designed to closely replicate the specific geological formation where the screen will be used. Fluids, typically oil or water, are then circulated through the assembly under carefully controlled conditions designed to mimic real-world production scenarios.

The key performance indicators during sand pack testing include sand retention capability, the screen's ability to resist plugging, and the resultant flow performance (Schuh, 1993). High sand retention capacity is crucial to prevent formation damage and loss of production, while resistance to plugging ensures long-term screen functionality.

Furthermore, sand pack tests can also evaluate the effect of various variables on the screen's performance, providing a more detailed picture of how screens will perform under different conditions. These variables include the grain size distribution of the formation sand, the properties of the fluid being produced, and the operational parameters, such as the flow rate and pressure (Tiffin et al., 2003).

By allowing a systematic examination of these factors, sand pack testing can provide vital data for engineers when selecting sand screens and designing comprehensive sand control strategies. As a result, sand pack tests contribute significantly to optimizing the productivity and lifespan of oil wells, making them an essential tool in petroleum engineering.

Both slurry and sand pack testing provide vital insights into sand screen performance and allow for more informed decisions in sand control management. However, it's crucial to recognize that laboratory tests cannot perfectly mimic downhole conditions. Hence, the results should be interpreted in conjunction with other available data, such as well logs, reservoir properties, and historical performance, to guide sand control strategy development (Penberthy & Shaughnessy, 1992).

6.0 Conclusion

Sand production is a complex problem in the field of petroleum engineering, one that can have severe consequences on the efficiency and longevity of oil wells. This paper has critically reviewed various sand control methods, their principles of operation, and their associated advantages and disadvantages.

The review has shown that the choice of sand control method is not a one-size-fits-all decision. Instead, it depends heavily on the nature of the reservoir, the rock mechanics, the type of formation, and the specific economic and operational constraints of the well. Thus, understanding the geomechanical properties of the rock, the in-situ stresses, and the flow properties of the reservoir fluids are crucial factors in designing the most effective sand control method for a specific well.

Among the techniques discussed, standalone screens and gravel packing have proven to be particularly effective for many applications. However, there is no universally "best" technique. Each has its strengths and weaknesses, and the optimal choice often depends on the specific circumstances and requirements of the well in question.

Moreover, while these techniques can help manage sand production, the issue of sand-induced erosion at the wellhead remains a significant concern. Thus, there is a need for more advanced sand control strategies and materials that can more effectively resist erosion while maintaining the necessary permeability for oil production.

This research underscores the need for further studies and technological advancements in the field of sand control in oil and gas production. Future work could focus on developing new materials and techniques for sand control, investigating the impact of new drilling technologies on sand production, or refining the mathematical and computational models used to predict and manage sand production.

In conclusion, sand control is a complex and multifaceted challenge in petroleum engineering. Its effective management requires a deep understanding of the underlying geological and mechanical processes, as well as a holistic view of the well's operational and economic context. Continued research and innovation in this field are critical for improving the safety, efficiency, and profitability of oil and gas extraction.

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