Sand Screen Selection

Many formations produce sand that may hinder production or damage completion and surface equipment. For decades, the industry has chosen sand control screens to address this threat based on traditional practices. Research suggests a new methodology that uses numerical simulation for selecting screen size and type may improve outcomes.

Adopting methods first used in water wells, early 20th century oil and gas operators concerned with potential sand production from unconsolidated formations completed wells using pipe that had slotted or round openings. The openings, placed across the production interval, were sized to prevent sand from entering the wellbore while minimally constricting fluid flow.

In time, the oil and gas industry developed sand retention methods that incorporated screens, resin- or plastic-coated particles and gravel packs. Some companies have, in recent years, sought to distinguish between sand management and sand retention, in which the former uses techniques such as orientation of the wellbore and perforations, monitoring and control of
well pressures, fluid rates and sand influx to limit sand production. Sand retention, or sand control, refers to the use of screens and other tools to reduce the risks of sand production without restricting oil and gas productivity.

Early sand control efforts centered on the assumption that choosing the optimal sand screen was based on a relationship between screen opening and a single point in grain size distributions. Experiments performed under ideal prepack test conditions using spheres of a single diameter led early researcher C.J. Coberly to conclude that negligible particle production occurs through rectangular slots of widths that are twice the particle diameter or through circular openings that have diameters three times that particle diameter (Figure 1).2

In formation sand samples, particles have a size distribution, which forced Coberly to pick a characteristic diameter, \( d \), within that size distribution based on physical experiments using formation sand samples. Sizing the slot width to twice \( d_{10} \) (2\( d_{10} \)) to allow negligible transient sand production is known as the Coberly rule. In response to Coberly's work, H.D. Wilson wrote that for sand samples from the US Gulf Coast, for example, proper retention of sand required sizing the slots to no larger than \( d_{10} \).³ Industry experts have concluded that the differences in those conclusions are related to what constitutes a negligible amount of produced sand and to the attempt to characterize the entire particle size distribution using a single parameter.

Other aspects of selecting a slot or screen size based on traditional practices involve taking representative sand samples and characterizing those samples. Most representative samples are obtained through conventional cores retrieved from known depths.

To characterize formations, laboratory technicians determine the particle size distributions (PSDs), typically by sieve or laser analysis or both. In recent years, the use of laser particle size analysis (LPDA) has become common in some companies because such analysis can better provide the details of the finer portion of the particle size distribution than can sieve analysis. In addition, laser analysis is less labor-intensive than sieve analysis and thus typically lower in cost, which allows operators to economically analyze many samples.

Using the most representative sample available, engineers typically determine proper screen openings based on the coarsest 10% of a particle size distribution, or \( d_{10} \). Screens that have slot widths determined by this process are designed to allow some amount of sand to pass while the coarsest particles are retained by size exclusion or bridging. In the process of retention, fine particles are retained by the pore space of the coarse grains and even finer particles retained between the pore space of the fine particles; this process repeats until sand production ceases.

This article describes the process by which engineers match optimal wire wrap and metal mesh stand-alone screen (SAS) size and type to target formations in openhole completions. In addition, this article discusses a technique that allows engineers to use the entire sand size distribution when selecting a screen and to quickly narrow the range of screen sizes and types to optimize sand control. This process often results in sand control decisions more suited to the well at hand than is possible using past practices that use only one design parameter, such as \( d_{10} \), and reduces the number of laboratory tests that must be performed to determine the optimal choice for the target formation. A case history from offshore West Africa demonstrates the potential for the methods discussed.

**How Choices Are Made**

Before the drill bit breaks ground, operators must make various decisions that will impact how the completion is finally configured. Engineers must then decide whether to case, cement and perforate the production interval or to use an openhole completion.

Openhole completions, typically less costly than cased hole completions, may be completed using gravel packs or stand-alone screens if the formation is expected to produce sand. Stand-alone screen types include wire wrap screens (WWSs) and metal mesh screens (MMSs). To create a WWS, manufacturers wrap wire around a perforated base pipe. The wire is either placed
around the pipe during manufacturing or manufactured as an individual jacket that is later welded to a base pipe. Mesh screens include one or more layers of woven stainless steel or mesh wire wrapped around a base pipe. The mesh, which acts as a filter, is covered by a protective shroud (Figure 2). Although uncommon, operators have included shrouds on WWSs in sidetracked wells that have challenging casing exits.

Even when widespread agreement exists that SASs are appropriate, recommendations for screen type and opening size often vary widely. Early efforts at screen sizing were based on a single point \(d_{10}\) on the PSD and some amount of sand production that was assumed to be acceptable, as described earlier.\(^4\)

In the 1990s, a mathematical model was developed to optimize sizing of slots in sand control devices. This model was based on a fractal description of the entire PSD given in terms of the number of particles rather than particle mass.\(^5\) A series of laboratory tests were performed to establish a database of wire wrap screen behavior results using sands from the North Sea and the Haltenbanken Area offshore Norway. From these experiments and the number-based particle size distributions, four slot widths were defined for each sand type tested: \(d_{--}, d_{--}, d_{+},\) and \(d_{++}\) (Figure 3). The designation \(d_{--}\) was the largest slot size at which severe plugging occurred and \(d_{++}\) was the smallest slot size at which continuous sand production occurred. The \(d_{--}\) and \(d_{+}\) slot widths were defined as the smallest hole size that did not allow plugging and the largest slot size that did not allow continuous sand production, respectively.\(^6\) The ideal slot size was stipulated to be between \(d_{--}\) and \(d_{+}\).

Completion engineers often use these criteria to constrain screen size options before performing sand retention tests (SRTs) in the laboratory to determine a final screen size. Two types of SRTs are available: slurry tests and prepack tests. Slurry tests are designed to replicate

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\(^4\) Coberly, reference 2.


\(^6\) Markestad et al, reference 5.


\(^8\) Chanpura et al, reference 7.

gradual failure of the rock surrounding the borehole (Figure 4). During slurry tests, a low-concentration slurry is pumped at a constant rate to form a sandpack around the screen. The mechanism of sand retention, therefore, is dictated only by particle size exclusion.

To perform prepack tests, which represent complete hole collapse, technicians place a sandpack on the screen and pump clean solids-free liquid through the pack. Because a sandpack is already in place, sand retention during a prepack test is achieved through both size exclusion and bridging.

Recent research has shown that current SRT setup and interpretation methods tend to favor one screen type or other. The traditional criteria used to choose between a gravel pack or an SAS are overly conservative and often lead analysts to opt for a gravel pack. Numerous experiments indicate that, contrary to accepted wisdom, screen plugging is rarely a problem in clean sand formations; when plugging is a threat as a result of other factors such as contaminated fluids, the risk can be mitigated through proper hole preparation procedures.

To address the variability and inconsistency inherent in screen selection and to better understand the physics of sand control, scientists recently used a numerical simulation approach to evaluate sand screen performance. The effort was part of a larger plan to produce a systematic screen selection process.

Screen sizing practices that relied on accepted standards were based on PSDs that did not use the results of sand retention tests. Despite the limitations of these standards, which are based on a few parameters of the formation sand size distribution and implicit assumptions about acceptable levels of sand production, most experts continue to use such standards not only to narrow screen size options but also to perform SRTs to confirm final screen selection.

In general, three results from SRTs are of interest: sand production correlated to the screen’s sand retention efficiency, pressure development correlated to screen plugging tendency and size distribution of produced particles with which to evaluate the risk of screen erosion. However, because it has now been established that screen plugging is rarely a problem in clean formation sand of any PSD, the main criteria for screen selection become transient sand production and PSD of produced particles. Engineers can determine both criteria using models developed in the last five years for specific screen and PSD combinations without having to conduct actual SRTs.

**Model Alternative**

A team from academia and industry reviewed recent screen testing advancements, interpretation and modeling for SAS applications. Based on its findings, the team has proposed a screen selection method based on laboratory test–verified numerical and analytical models.

The primary purpose of this method is to eliminate or reduce the number of physical SRTs that must be performed when selecting a screen size and type for a given application and to better understand the science of sand retention. The study used numerical SRT simulations that matched experimental data in an effort to aid the team in understanding and relating PSD-screen combinations and to correlating sand production with formation sand PSD until sand production stops or is limited to fines.

The team first studied WWSs, which have a simpler geometry than that of other screen types, and performed simulations using the discrete element method (DEM). This numerical model describes mechanical behaviors, such as mass,
velocity, force and angular momentum, of assemblies of spheres (Figure 5). The study simulated prepack experiments by first generating a packing of polydisperse granular spheres over a wire wrap screen geometry and then flowing a fluid through the pack. The research team could then compute the mass of sand produced per unit area of screen for various screen sizes and PSDs.

To accurately represent the physics of the problem, the model was tested and validated using a range of various parameters. The team found that friction and shear forces are necessary to form stable particle bridges, whereas the most critical parameter affecting the number of sand particles produced is the ratio of the slot width to particle diameter. Similarly, high fluid viscosities and low pressure gradients facilitate particle bridging; increased fluid pressure increases particle production when pressure gradients are up to about 2.3 MPa/m [100 psi/ft]. At higher gradients, however, there is no such dependence.

When the results from the DEM model were plotted, the team observed a power-law relation. This relationship was confirmed by plotting the experimental data, which revealed excellent agreement and consistent trends between model and experimental results. Based on this newly established relation, the team developed the Mondal-Sharma (M-S) method, which uses the number and size of the produced solids to estimate the mass of sand produced (Figure 6). When comparing the estimated mass of sand produced using the M-S method with the mass of sand produced in experiments, a good match was found. The M-S method, which uses DEM simulation results to develop a simple correlation, can be used to estimate the mass of sand produced without performing DEM simulations for every possible sand and screen combination.

The research team next extended the application of the M-S method to include plain square mesh (PSM) screens, achieving much the same outcomes. Some conclusions from WWS and PSM simulations included the following:

- Simulations are able to estimate the mass of sand produced for a given PSD and screen size.
- Simulations results strongly agree with those from carefully controlled prepack experiments.
- Simulations show that the mass of sand produced per unit screen area and for unit open flow area is larger for single layer PSMs than for slot geometry of the same rating and corresponding standard open flow area.
- Simulations show that the ratio of wire thickness to opening size seems to be a key factor contributing to the increased mass of sand production from single layer PSMs.

Researchers then turned their attention to analytical solutions and Monte Carlo simulations to predict sand production through WWSs and PSM screens under slurry test conditions. Their results showed that the analytical solution and the numerical simulation were in excellent agreement. The team showed that its proposed methods were able to estimate both mass and size distribution of the produced solid in a slurry-type SRT, taking into account the full PSD of formation sand. Simulations also showed that, with the exception of a mobile fines problem, sand
production becomes negligible once the slot opening has been covered by particles larger than the opening (Figure 7).

As in the case of modeling prepack-type SRTs, the proposed methods can be used to estimate sand production in slurry-type SRTs for various screen sizes, thereby enabling screen size selection based on an acceptable level of sand production. Final screen selection may then be confirmed through a slurry-type SRT. Results showed that more than 90% of the total sand production by mass occurs during the formation of the first layer of particles on the screen and that the PSD of the retained sand approaches that of the formation sand after a few layers of sand accumulate on the screen.

Results also revealed that the mass of sand produced during the formation of the first layer of particles on the screen is independent of the shape of the PSD for grains smaller than the aperture-pore size and is governed by the shape

Figure 6. Determining mass of sand produced and entire formation particle size distribution. The Mondal-Sharma (M-S) method uses a correlation between the number of particles of diameter $D_p$ produced through a screen slot opening of width, $W$. The number of particles of each diameter produced through the screen are counted and plotted against $D_p/W$ from every simulation (top). In this case, formation PSDs A and B were distributed into five bin sizes each (bottom, dashed lines) to generate the number-based size distributions ($D_{1A}$ to $D_{5A}$ and $D_{1B}$ to $D_{5B}$) used to populate the simulation box (bottom). (Adapted from Mondal et al, reference 9.)

of the PSD of grains greater than the aperture-pore size. In addition, researchers found that sand production through the filter layer of a PSM screen of a given pore size is greater than that of a WWS of the same slot size (Figure 8).14

The Mythology of Screen Selection
The team's work has cast doubt on, or added qualifications to, numerous widely held industry beliefs about WWSs and PSMs. These axioms, upon which many traditional screen selection methodologies for SASs have been based, include the contention that formation sand plugs screens. However, research has shown that following SRTs, when only trapped particles remained on the screens, final screen permeability was in the range of 5% to 100% of original screen permeability; the final value, then, of even the low-permeability SAS screens, which have an original screen permeability of about 300 D, would be a minimum 15 D. The screen permeability is thus significantly higher than most formations and thus too great to cause plugging; plugging is commonly quantified by a pressure differential created across the screen. Instead, plugging more likely occurs as the result of poorly conditioned mud or filtercake mixed with formation sand, mixed coarse and fine formation sands from a variety of zones or clay and shale mixed with formation sand.15

PSD and PoSD
When SRTs are performed in the laboratory using formation sand, the sand PSD is often not needed. However, PSD is required if there is a large spread in formation PSD along the well, or if the SRT is performed using a sample that was generated based on specified PSD or if a model is used to estimate sand production for a given sand PSD–screen combination. Particle size distribution of formation sand is typically determined through dry sieve analysis or laser particle size analysis (LPSA).16

Dry sieve analyses determine PSD through a mechanical separation of particles by filtering them from top to bottom through a series of progressively finer sieves. The measured weight of the sand captured in each sieve is used to calculate cumulative percentage mass of each, which is then plotted against sieve size on a semilogarithmic scale.

Laser particle size analyses determine PSD by measuring how light is scattered as a laser beam is passed through a sand sample. The angle of scatter is inversely proportional to the particle size.17 To ensure that the sand samples are delivered to the measurement device in the correct concentration and in a stable state, LPSA is performed on samples whose dispersion is controlled by dry or, when necessary, fluid dispersants.

Sand control experts have long used dry sieve and LPSA nearly indiscriminately, and persistent differences in the results obtained from the two methods have been well documented. Recent research indicates these inconsistencies may be caused by the aspherical shape of the particles, sampling practices for LPSA, fluids used and various light blocking levels used in the LPSA. Based on these observations, PSD determined by dry sieve analysis is recommended for both slurry-type SRT testing and sand production prediction using the above

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15. This research revealed that numerous assumptions regarding sand production and screen characteristics were unfounded. For more on the team’s discussion of traditional assumptions: Chanpura RA, Mondal S, Sharma MM, Andrews JS, Mathisen A-M, Martin F, Marpaung F, Ayoub JA and Parlar M: “Unraveling the Myths Associated with Selecting Standalone Screens and a New Methodology for Sand-Control Applications,” SPE Drilling & Completion 28, no. 3 (September 2013): 227–236.
models. However, errors or differences attributed to particle shape differences may still occur. These differences may be minimized by characterizing the particle shape and aspect.

Recent investigations of mesh screens have highlighted the need to account for screen complexity from layered design when modeling sand production. Using microcomputed tomography (microCT) images, researchers constructed 3D images of two metal mesh screen types: PSM and plain Dutch weave (PDW) (Figure 9). These 3D images of virtual screens were validated by comparison with the microCT images.

The team then conducted DEM simulations that were validated by experiments of prepack SRTs through multilayer PSMs and PDWs. Analyses of microCT scan meshes indicated that mesh screen layers overlap significantly and thus impact retention efficiency. The group developed a method to calculate the retention pore size distribution (PoSD) and effective pore size for a given overlap of PSM samples. The calculated PoSD can be used in the analytical model to improve sand production prediction in a slurry-type SRT.

As a consequence of this work, the performance of nominal size MMSs can be simulated using any reservoir sand size distribution. To date, because the team has been able to characterize PSMs, operators are able to evaluate a large number of PSMs in a short time and thus reduce the number of SRTs that must be run to choose the optimal screen size for a given reservoir. In time, this work will be expanded to include additional screen types.

By the Numbers

Engineers use SRTs to choose the optimal screen from a range of screens selected based on a relationship between screen openings and grain sizes. Although SRT results can be impacted significantly by relatively small changes to test conditions, when performed properly, the SRT is widely considered a reliable method for finalizing screen choice. The drawback to this process, however, lies in the dubious traditional practices used to narrow the range of screen choices and in misinterpretation of pressure developments in standard SRT experiments. This process often forces operators to choose to perform many time-consuming SRTs before qualifying a screen as optimal for long horizontal sections that have varying sand PSD.

By replacing traditional methods with numerical and analytical models, operators may reduce and eventually eliminate the dependence on SRTs. In addition, because traditional screen selection methodology tends to be conservative, a software-based approach may allow operators to opt for SASs over gravel packs, which are typically more expensive.

When working offshore West Africa required sand control for a nonuniform unconsolidated formation, a major operator based its screen selection process on traditional $d_{50}$ preselection criteria and on SRTs for finalizing its selection. The completions team also compared the results of the laboratory tests to numerical models.

The targeted reservoir is the second sand in the offshore field; wells in the first sand of the field were completed using sand control devices selected based solely on traditional methods. However, the first formation produced is made up of highly uniform, well-sorted reservoir sands that have very low levels of fines content. By contrast, the targeted sand in the second reservoir is much less uniform, poorly sorted and has higher fines content. In the face of these adverse sand control indicators, the operator opted to perform as rigorous a selection process as possible and to check selections based on traditional and SRT methods against those using simulations and mathematical models.

In comparing results, the operator concluded that selections based on the results of SRTs and those based on the mathematical models matched closely. The operator added that although models require laboratory data for proper calibration, they held significant potential for aiding screen size selection without the need for continued laboratory testing when applied in regions for which extensive SRT data existed.

The quantity of and interaction between the variables that engineers must consider in choosing a sand control strategy can be daunting. For decades, engineers have relied on the experience of their predecessors to help them sort the data and arrive at decisions. Today, however, because of the growth of computing power and capacity, operators may avail themselves of more accurate and less compromising methods for sand control selection. Based on physics and mathematics, these new methods promise not only a quicker, less costly path through the selection process, but one that provides engineers with the certainty that they have chosen an optimal sand control strategy for any given formation. —RvF