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A Comprehensive Review of Sand Retention Test Methods and Data Analysis with a Focus of Application

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Abstract

Sand Control completions in long horizontal laterals often present challenging conditions because of a wide range of formation particle sizes and inflow rates which must be contained with a single completion. To aid in the screen selection process, laboratory testing of possible sand control media has proven to be a reliable method to improve the success of the completion.

Soft sand completions are generally characterized into two classes of wellbore environments. A rapid wellbore collapse onto the screen or a gradual mechanical failure of the surrounding formation. Depending upon the type of wellbore environment encountered, one sand control test may provide a closer simulation to the failure phenomenon in the wellbore than another.

This paper reviews three primary types of sand retention tests that include Constant Drawdown (pre-pack), Constant Rate, and Cyclical Brine. There are several variations on each test method, particularly the constant rate test method.

The primary objective of any sand retention test method is to determine the amount and size of solids production through the sand control media with a specific particle size distribution. However, the various test methods provide additional performance data to aid in selecting a sand control system for a given environment. The Constant Drawdown method simulates a wellbore that is in conformance with the sand control media. This method provides retained screen permeability, as well as the formation and system permeabilities at multiple stress levels. Similarly, the Cyclical Brine method simulates a rapid wellbore collapse with an emphasis on injection well shut ins. This test provides system permeability data in both the injection and production flow directions. Lastly, the Constant Rate methods simulate a gradual or erosional failure of the wellbore on the sand control media. In these tests, a fluidized slurry contacts the sand control media in the open annulus, providing increasing pressure data with time.

Using the sand retention data from these test methods a master curve is generated, which can predict how the screen will perform with various particle size distributions. A detailed analysis of particle size data down a lateral and interpretation with the Master Curves has been completed and provides a prediction of the performance of the sand retention media across the range of formation particle size distributions.

By comparing the various evaluation methods through a reproducible sand retention study, we can optimize laboratory evaluation methods for a variety of wellbore environments. This provides the industry a

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comprehensive guide for matching wellbore specifications to the ideal laboratory sand retention evaluation method, optimizing the sand control selection to the well.

Introduction

In today's operational climate, soft sand or poorly consolidated completions have become commonplace. In many highly productive regions, soft sand completions are the dominant type of completion. This presents unique challenges in the planning and development of new wells, such as controlling potential solids production. Sand production can quickly become a costly problem leading to eroded hardware, reduced well productivity, blocked tubulars, and additional operational costs on the surface.

To combat sand production in high-risk completions, the industry has proven that by implementing a sand control device the produced solids can be controlled while optimizing well performance. The quantifiable objective of placing a sand control system in the wellbore is to lower solids production to an acceptable standard by the use of filter media. The sand control system also protects against a catastrophic failure of the wellbore.

Due to the need for an effective sand control system, a multitude of vendors have developed products for the market. However, each vendor and their specific product is designed to be effective within a given formation particle size. Even if the formation particle size distributions in the well are known, it is a risk to select a screen or screen and gravel pack based solely on the vendor's numerical rating. While vendors typically provide a micron rating for their screens, this is a nominal micron rating and not a true micron rating (Underdown, 1999). Bridging of the formation on the sand control media is highly influenced by the size and shape of the formation (Fischer, 2014). This means even if the micron rating a vendor provides is accurate, it is not a clear indication of sand control and production performance. The most effective way to get accurate and reproducible sand control data is by conducting laboratory testing, where a representative formation particle size distribution is challenged against a specific sand control test media.

Due to the risk of using screen performance specifications supplied by vendors, companies have developed in-depth sand control system qualification processes. These procedures utilize laboratory evaluation techniques to provide key operational data, aiming to mitigate risk during well design (Adams, 2009). In the laboratory, sand control system performance can be directly evaluated for criteria such as sand control, flow capacity, and resistance to structural deterioration.

In this paper, a comparative evaluation is made for several sand control and screen performance testing methods used in well design and how they can be optimized to match specific well environments. The goal of any screen selection process is to determine the optimal screen for a given reservoir, where solids are controlled with minimal loss to well productivity (Chanpura, 2011). However, by matching the evaluation method to the wellbore environment of a given completion, operators will have the correct data for selecting an effective sand control system.

Wellbore Instability Background

Within the industry today, the Constant Drawdown (also called Pre-pack) and Constant Rate (also called Slurry) test methods have become the two leading types of laboratory sand control evaluation methods, each of which are suited for different wellbore stability conditions. The Constant Drawdown evaluation method is used to simulate a rapid collapse of the wellbore onto the sand control system, such as a pore collapse or comprehensive failure during production drawdown. This method is also applicable for sand control systems that are in conformance with the wellbore such as expandable screens or gravel packs. The Constant Rate evaluation method is used to simulate a gradual or erosional failure, where the surrounding formation is deposited onto the sand control device by means of a fluidized slurry over time, commonly occurring during fluid circulation.

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As the in-situ stresses on the formation are changed from completion and production processes, wellbore instability problems such as sand production, collapse, and loss of circulation can occur (Aadnoy, 2010). To deploy counteractive measures, the industry has developed multiple failure criterion models and data collection methods to predict the severity of possible well instability (Swarnanto, 2018). Once the formation properties and predicted wellbore stability are established, the selection process for preventive technology can be optimized by matching the laboratory testing methods to the predicted wellbore instability.

Formation Selection

For accurate laboratory sand control data, the importance of the selection of appropriate test formation sands cannot be over-stated. The formation sands to be tested should be representative of those found in the entirety of the wellbore. The test sands should not be "cherry-picked" nor limited to the "best" (largest, most uniform) sands nor the "worst (smallest, most non-uniform) sands.

Instead, the sands chosen for testing should represent the entirety of the sand distributions found in the target completion. Such an analysis leads to the highest probability of success for both the testing program and ultimately, the completion. The selection of only the "best" sands can lead to the incorrect selection of sand control.

All available particle size data should be analyzed for formations to be recommended for laboratory testing. Constien defines the effective formation size as the median grain size (d50) divided by the uniformity coefficient (d40/d90) (2006). This effective formation size has been shown to provide an accurate way of determining what ratios of formation particle sizes to screen opening sizes optimally control sand production for a given formation particle size distribution range (Fischer, 2016).

To further assist with formation selection, a frequency analysis is performed on the particle size data. The goal of the frequency analysis is to collapse the distributions to a single line for analysis. The frequency plot is created as follows:

1. Ensure that data is presented in largest to smallest fashion (largest particle as d10).
2. Verify the d40, d50, and d90 are presented in micron. Re-calculate if provided in millimeters.
3. Calculate the uniformity coefficient for each distribution (d40/d90).
4. Calculate the effective formation size for each distribution (d50/UC).
5. Sort the effective formation sizes from smallest to largest and assign each distribution a numerical ranking for the total number of distributions. (The smallest distribution will be #1, etc).
6. Calculate the frequency of each distribution by dividing it's ranking by the total number of distributions and multiply by 100.
7. Plot the frequency for each distribution vs. the effective formation size.
8. Select the distributions for testing.

Illustrated below is an example data set. From Figure 1, three formations were identified for further analysis in sand retention testing. The selections were designed to provide a range of distributions for testing that would be representative of the range of distributions present in the producing interval. Table 2 below provides the recommended formations. The formations selected provide a range of Formation d50/UC ratios.

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Table 1—Formation Samples Particle Size Data

Cumulative Weight Percent Larger Than (micron):							Uniformity Coefficient (d40/d90)	Formation d50 / UC
d10	d25	d40	d50	d60	d75	d90		
370	287	237	200	152	69	7.5	31.6	6.33
413	307	239	205	172	103	6.9	34.6	5.92

Cumulative Weight Percent Larger Than (micron):							Uniformity Coefficient (d40/d90)	Formation d50 / UC
d10	d25	d40	d50	d60	d75	d90		
27.8	15.4	9.2	6.3	4.3	2.4	1.1	8.4	0.75
324	248	196	162	129	59	6.7	29.3	5.53
412	294	230	198	168	107	12.3	18.7	10.59
402	294	233	200	167	117	17.3	13.5	14.81
384	300	230	199	168	81	8.4	27.4	7.26
418	319	258	215	177	118	13.2	19.5	11.03
420	323	252	221	189	130	21.3	11.8	18.73
52	30	14	8.6	5.5	2.8	1.3	10.8	0.80
36	18	10	6.6	4.5	2.3	1.0	10.0	0.66
469	337	267	226	193	113	9.4	28.4	7.96
404	295	229	191	160	99	9.8	23.4	8.16
28	16	9.0	6.0	4.0	2.2	1.1	8.2	0.73
15	8.2	4.9	3.6	2.7	1.7	0.9	5.4	0.67
12	6.3	3.9	2.9	2.3	1.5	0.9	4.3	0.67
473	353	282	242	212	164	20.1	14.0	17.29
640	431	334	295	258	167	13.6	24.6	12.0
34	15	8.3	5.5	3.8	2.2	1.1	7.5	0.73
431	299	230	193	158	83	5.0	46.0	4.20
487	361	276	227	173	29	3.5	78.9	2.88
549	396	308	261	216	141	14.2	21.7	12.03
485	358	281	238	194	112	11.8	23.8	10.0
594	421	315	256	202	123	16.8	18.8	13.62
376	263	205	177	150	102	10.8	19.0	9.32
183	135	81	52	28	8.0	2.0	40.5	1.28
262	192	158	139	118	57	7.5	21.1	6.59
189	150	107	69	39	12.2	2.7	39.6	1.74
201	151	110	76	42	11	2.7	40.7	1.87

Table 2—Selected Formations for Testing – Only one PSD from each frequency

Percentile from Frequency Plot	Formation d50	Formation UC	d50 / uc
20th	5.5 6.3 8.6	7.5 8.4 10.8	0.73 0.75 0.80
50th	200 199	31.6 27.4	6.33 7.26
80th	295 264	24.6 21.7	11.99 12.03

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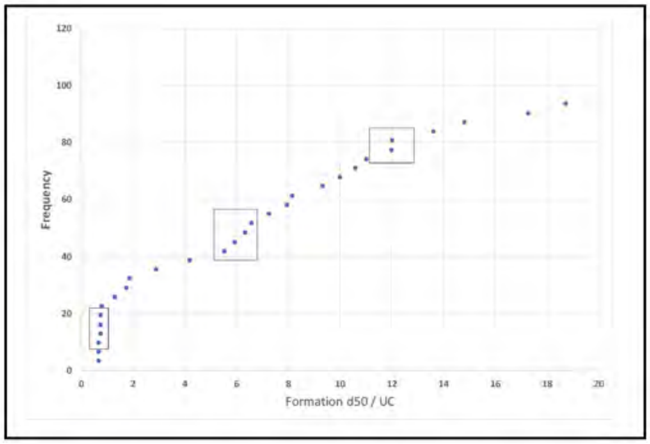

Figure 1—Frequency Plot – Formation Selection

Overview of Sand Retention Test Methods

Constant Drawdown Test Method

The Constant Drawdown (CDD) test method simulates a well environment where the formation is in conformance with the sand control system, whether due to a rapid formation collapse or filling the open annulus with a gravel pack or expandable screen. During the initial stage of the test, a formation pack roughly 0.5 inches in thickness is collapsed onto the test media, which simulates the filling of the annulus between the sand control device and wellbore. This is achieved by thoroughly mixing the test formation in a viscous Newtonian oil and pre-packing the concentrated slurry into the cell, as shown in Figure 2. The test oil is flowed through the formation and sand control system at a constant drawdown pressure of 200 PSI. Due to the way the formation is mixed and pre-packed into the cell, formation sorting as the particles approach the sand control system is minimized so the particle size distribution in conformance with the test media is a true representation of the measured bulk particle size distribution. Pressure surges across the formation and screen of 0-400 psi are applied when approximately 0.75 gals of oil / ft^2 screen area has passed through the screen. This pressure surge is done after the bridging and arching is stable to simulate shut-in of the well. After about 3 gallons of oil / ft^2 of screen surface has been produced through the formation and test media, the net uniaxial stress is then increased from 200 psi to 1000 psi over three stages. This simulates the environment after the annulus area has been filled with formation material and the wellbore stresses increase on the formation and sand control system.

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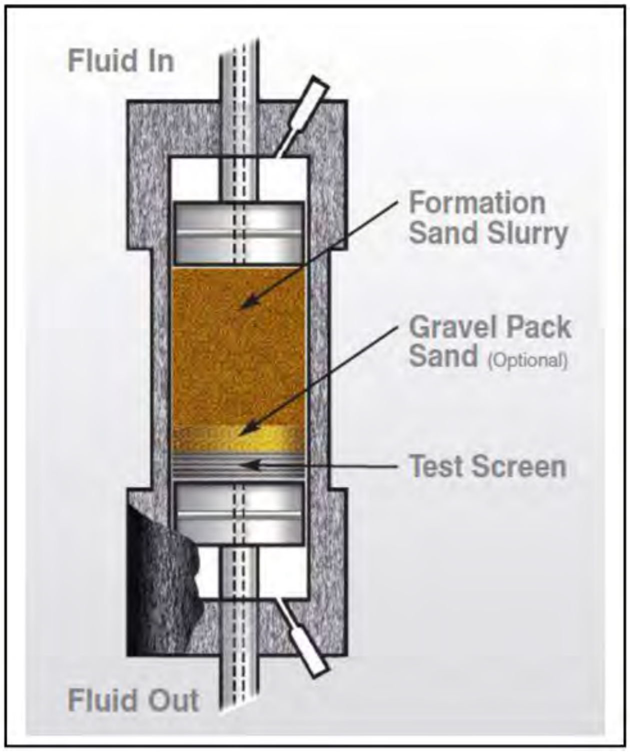

Figure 2—Constant Drawdown Test Cell Schematic (Fuller, 2019)

Additionally, the change in the flow capacity with stress for the formation and sand control system is determined as the test oil flows through the system at a constant drawdown pressure of 200 PSI. These values can be used in radial in-flow modeling to estimate productivity and assist in well design (Gurley, 2022). It should be noted that the permeability values calculated in the Constant Drawdown test are best-case scenario with no loss of permeability from the remaining mud filtercake.

The Constant Drawdown method as shown in Table 4, provides the most screen performance evaluation data for both sand control and permeability. During the initial stage, samples of the oil with produced solids passing through the screen are collected at regular volumes and the concentration of solids is determined as a function of pounds of formation / ft^2 of screen area versus total flow / ft^2 of screen area. The particle size distribution of the produced solids is also determined and directly compared to the original pre-test formation particle size distribution. At the conclusion of the test, the test media is cleared of formation and a retained screen permeability is measured.

Constant Rate Test Method

The Constant Rate (CR) test method simulates an erosional or gradual wellbore failure, where the surrounding formation is gradually deposited onto the sand control media by a fluidized slurry. The Constant Rate method uses a formation injection cylinder placed perpendicular to a slot flow cell, that injects the highly concentrated slurry into a brine flow stream diluting the solids concentration, as shown in Figure 3. The formation material is injected into the brine stream just before it enters the test cell at 0.5 – 1.0 percent by volume solids. Due to the injection design, brine flow rate and formation injection rate can be modified to match specific well conditions though the typical rate is 200 mL/min. Throughout the entirety of the test, a constant rate of deposition is maintained until the maximum pressure drop of 200 psi is achieved or all the formation is deposited onto the test media at a specific volume. The time it takes to get to the 200-psi threshold is controlled by the amount of sand production and changes in flow capacity.

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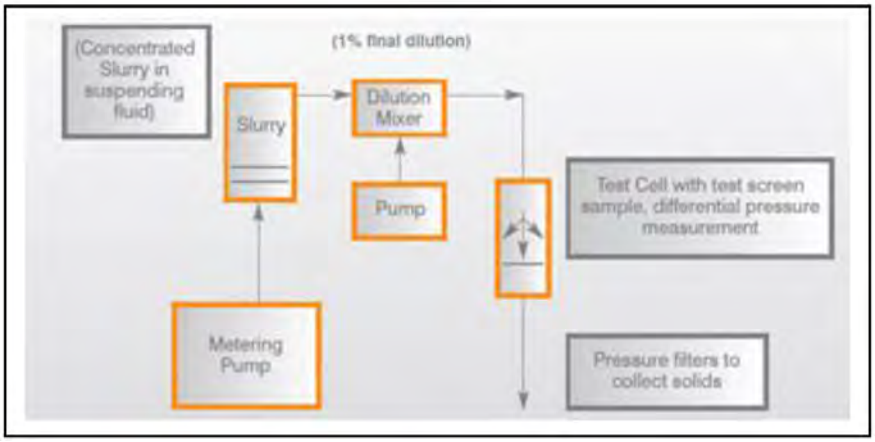

Figure 3—Constant Rate Flow Schematic (Fischer, 2018)

The Constant Rate method as shown in Table 4, provides key data designed to evaluate the screens' sand control performance and retained permeability. As the slurried flow contacts the screen the formation that is produced through the screen is collected in volumetric beakers. Using the volumetric samples, the particle size distribution and total produced solids is determined as a function of pounds of formation / ft^2 of screen area versus total flow / ft^2 of screen area. As fluid passes through the test media the retained formation will start to build pressure across the test media and formation. Throughout the test, the pressure drop across the test media is continually recorded and is plotted as pressure versus total volume. After the test is completed, the final screen permeability is determined and compared to the initial permeability.

Screen Efficiency Test Method

The Screen Efficiency Test (SET) method is a very dilute constant rate test that utilizes a slurry to deliver formation to the sand control test device at a constant rate, simulating a wellbore environment similar to the Constant Rate Test. Unique to the Screen Efficiency Test method, the slurry concentration and rate are variable between test sets. Due to the variability of the concentration and rate, a calibration test is required before the onset of testing. The goal of the calibration test is to identify the concentration and rate at which the bulk of the test screens will reach the standard of 100 psi at the completion of the test, for a selected formation (Underdown, 1999). Typically, concentration ranges are determined to be between 0.02 – 2.0 grams/Liter, with flow rates of 10 – 500 mL/min. Once the conditions are determined, all sand control devices are tested against the selected concentration and flow rate for the entire set. However, due to test condition variability, only screens within the same test set can be directly compared for performance.

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Figure 4—Screen Efficiency Test Cell Schematic

The Screen Efficiency Test method evaluates the screen performance by measuring the solids production and flow capacity changes as formation deposition occurs onto the screen. Throughout the entirety of the test, volumetric samples are collected, and the solids are extracted to determine the total produced solids. Flow capacity changes are measured as pressure increases in proportion with formation deposition onto the screen. As the formation pack length increases the pressure required for a constant flow rate through the pack is subsequently increased.

Cyclical Brine Test Method

The Cyclical Brine (CB) test method is a constant drawdown brine test that simulates an environment where alternating directions of flow may occur, such as when an injection well is shut in. Comparable to the Constant Drawdown test method, the initial stage emulates a rapid collapse of the wellbore formation onto the sand control device. After the formation has fully collapsed onto the test media, a roughly 0.5-inch-thick formation pack is formed. Once the pack is in conformance with the test media the confining stage is initiated as the uniaxial confining stress is increased to a 700-psi differential. The flow rate of brine through the screen in the production direction is started and pressure and rate are continuously monitored. As with the previous test methods, volumetric samples of the brine with produced solids passing through the screen are collected in production direction and the concentration of solids is determined as a function of pounds of formation / ft^2 of screen area versus total flow / ft^2 of screen area. Once the specified volume is reached, the brine flow is switched to injection direction, as shown in Figure 6. This production and injection cycle are then repeated twice over, for a total of three production and injection flow cycles. Throughout the entirety of the test, the pressure and flow rate are continuously monitored. During injection flow, no sand is allowed to produce through the top confining screen, just as no sand production would occur in the well.

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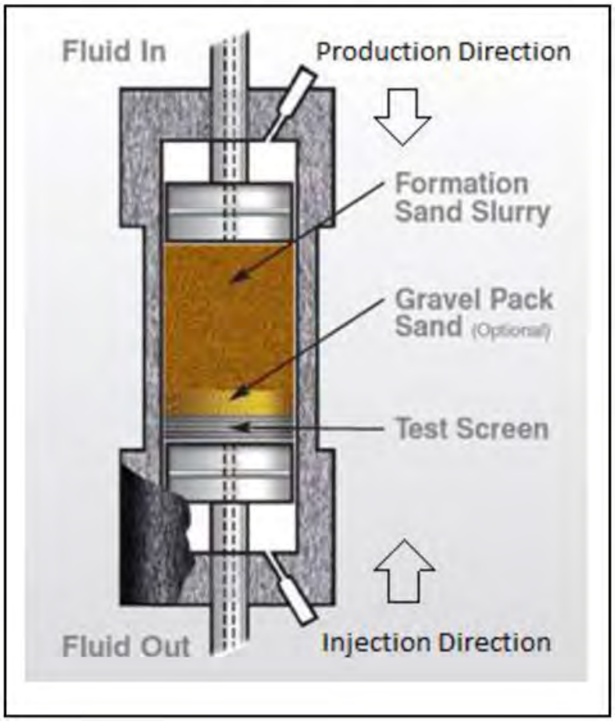

Figure 5—Cyclical Brine Test Cell Schematic

By taking flow data in both the production and injection directions the formation and system permeability can be measured in both directions, as shown in Table 4. The permeability of the formation plus test media is determined at 700-psi net stress in the cyclical brine test. At the conclusion of the test, the final screen permeability is determined and compared with the initial screen permeability.

Comparative Data and Discussion

For this paper, all test methods were used with both a wire-wrap and a premium mesh screen rated at a micron opening size of 175-micron. The same formation sand was tested across all methods and screens to provide a comparison of results from the various test methods. The primary objective of each test method is to evaluate the ability of a sand control device to limit solids production while retaining flow capacity performance. The formation selected for the comparative test evaluation is shown in Table 3. Table 4 provides a summary of the data collected by each test method and the wellbore environment that is most accurately simulated.

By conducting this reproducible laboratory study with comparable formation and screen variables, a clear correlation can be made across the test methods. Additionally, this study indicates the quality and quantity of data provided by each test and how they can be applied to match the type of wellbore failure expected in the field.

Table 3—Formation Particle Size Distribution

Formation Sample #	Cumulative Weight Percent Larger Than (micron):							Uniformity Coefficient (d40/d90)
	d10	d25	d40	d50	d60	d75	d90	
Test Sand	283	223	186	166	145	107	24.8	7.5

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Table 4—Comparison of Test Methods

Property	Constant Drawdown Oil-Flow Test (CDOF) Screen only or Gravel Pack	Constant Flow Rate Brine Test (CFRB) Screen Only	Constant Flow Rate Brine (SET) Screen Only	Cyclical Brine Test (Constant Drawdown)
Fluid	Newtonian Oil	Brine (3% KCl or specified fluid)	Glycerin (34cP)	Brine (3% KCl or specified fluid)
Type of Failure Simulated	Complete collapse of wellbore onto screen and / or sand control in conformance with the wellbore such as expandable screen or gravel pack	Erosional Failure	Erosional Failure	Injection well with complete collapse of wellbore onto screen and / or sand control in conformance with the wellbore such as expandable screen or gravel pack
Drawdown Pressure across the screen or gravel pack	200 psi	Variable, maximum is 200 psi	Variable, maximum is 100 psi	Up to 200 psi, may be less if very permeable formation
Flow Rate across the screen or gravel pack	Variable, dependent upon formation permeability and amount of solids produced	200 ml/min	Up to 200 ml/min, set by calibration test to achieve 100psi in one hour or less	Variable, dependent upon formation permeability and amount of solids produced
Solids Concentration		0.5% by volume	0.02 – 2 gr/L, set by calibration test to achieve 100psi in one hour or less	
Initial and Final Screen Permeability Measured	Yes	Yes	No Screen Permeability Measurement	Yes
Amount of Solids Produced through the screen or gravel pack	Yes (always reported at 3 gal/ft^2 of flow)	Yes Solids production collected by flow increments until maximum pressure is reached. Total solids production may not always be at same volume through screen if pressure increases rapidly and test must be shut down before completion	Yes Solids production collected by flow increments until maximum pressure is reached. Total solids production may not always be at same volume through screen if pressure increases rapidly and test must be shut down before completion	Yes (always reported at 3 gal/ft^2 of flow)
Size of Solids Produced through the screen or gravel pack	Yes (reported at 0.25gal/ft^2 of flow through the screen)	Yes (reported at 3 gal/ft^2 of flow through the screen)	Yes	Yes
Permeability of Formation and Screen	Yes, pack length is constantly measured, flow rate is measured, DP is measured. Permeability measured vs. stress up to 1000psi net confining stress	No formation permeability measurement	No formation permeability measurement	Yes, pack length is constantly measured, flow rate is measured, DP is measured. Permeability measured vs. stress at 700psi net confining stress

Produced Solids and Particle Size Distribution Data

For all of the testing methods the quantity and size of the produced solids are measured. As discussed in the methods description, volumetric fluid samples with produced solids that passed through the screen are collected and the concentration of solids is determined as a function of pounds of formation / ft^2 of screen area versus total flow / ft^2 of screen area. The total solids production is reported as Produced Formation versus Total Flow Volume, shown in Figures 7, 9, 11, 13. The measurement of the particle size for the produced solids is limited by the quantity of solids produced. Typically, there are only enough produced solids from the first one or two sampling points in the test that allows particle size distribution data to be measured, shown in Figures 6, 8, 10, 12. It should be noted that the quantity of produced solids drops rapidly as the test progresses. When the screen or gravel pack is sized appropriately for the formation, the bridging and arching quickly stabilizes, and produced solids through the system becomes so low that they are no longer measurable in the lab. This type of bridging was observed in all tests across the methods to varying degrees, where the sand production is quickly controlled after the first few sampling intervals. For

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the Constant Drawdown method, the size of the solids produced through the screen after ~ 0.25 gal / ft^2 of flow is measured, as shown in Figure 6. The 0.25 gal / ft^2 of flow is typically the flow volume at which the most solids are produced.

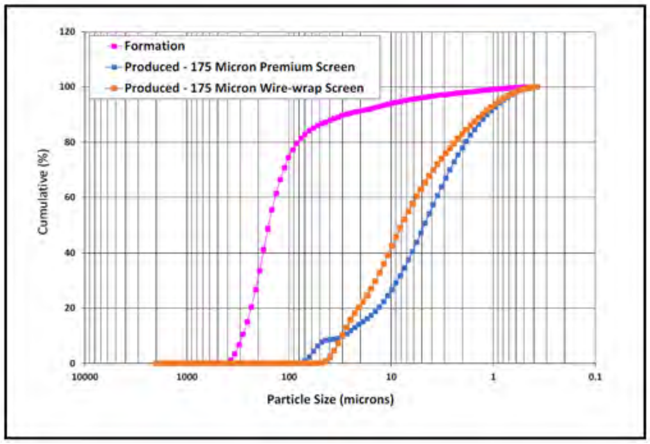

Figure 6—Formation and Produced Particle Size Constant Drawdown Test

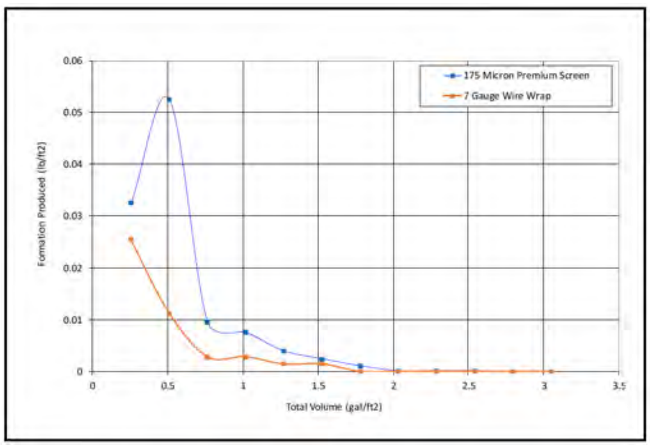

Figure 7—Produced Formation vs. Volume Constant Drawdown Test

For Constant Rate and Cyclical Brine, the size of the solids produced through the screen after ~ 3.0 gal / ft^2 of flow is measured, as shown in Figures 8 & 10. The 3.0 gal / ft^2 of flow is typically the flow volume at which the largest quantity of solids production occurs. Additionally, if sufficient solids are produced during subsequent production direction flow in the Cyclical Brine test, the size of the solids produced is also measured. For this test series, there was insufficient solids production from the Cyclical Brine second and third production direction flow stages and Constant Rate premium screen test for the solids particle size to be measured.

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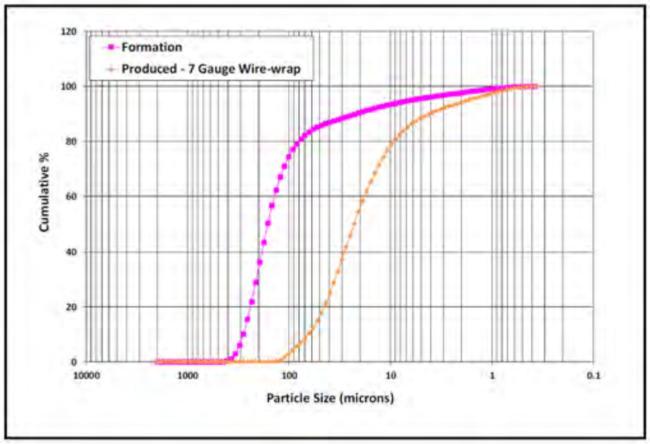

Figure 8—Formation and Produced Particle Size Constant Rate

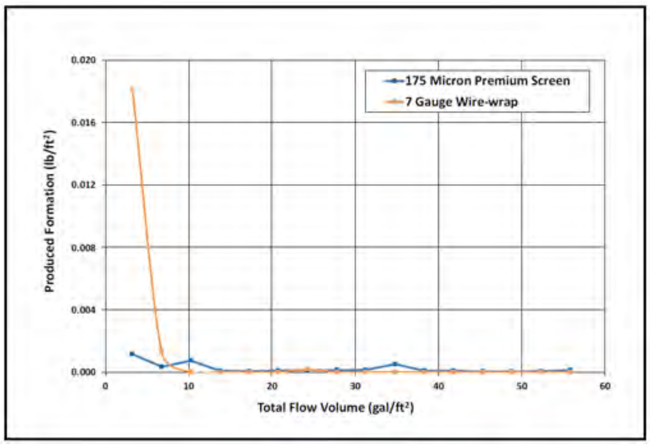

Figure 9—Produced Formation vs. Volume Constant Rate

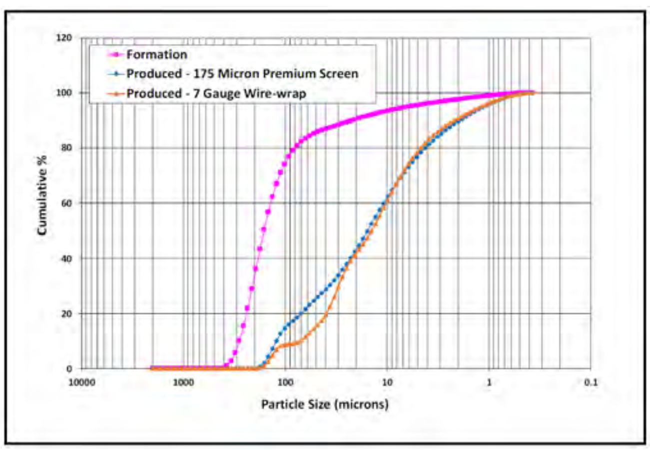

Figure 10—Formation and Produced Particle Size Cyclical Brine

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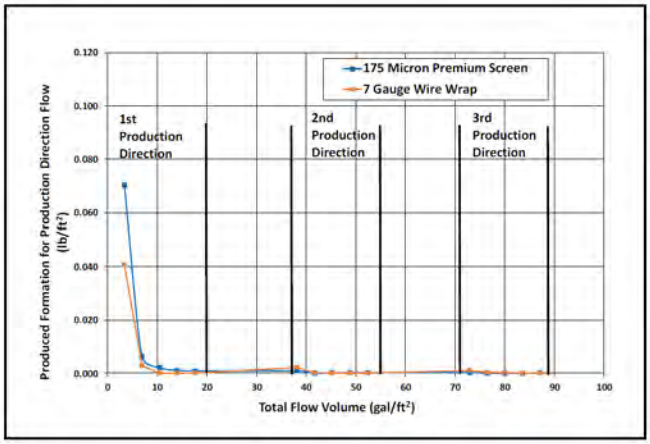

Figure 11—Produced Formation vs. Volume Cyclical Brine

In the Screen Efficiency Test, the total produced solids are highly dependent on the total volume challenged as the wire wrap did not produce sufficient solids for the particle size to be measured, as shown in Figure 12. This presents a challenge when looking at total produced solids from one test to another, both in a set with high extreme spreads for the time to reach 100 psi and from set to set. In the case of Figure 13, the 7-gauge wire wrap and 175 premium mesh screens had an extreme spread of 50 minutes, equating to a roughly 90+% volume disparity between the screens in the set. Due to the difference in total solids challenged the premium mesh screen produced substantially more than the wire wrap.

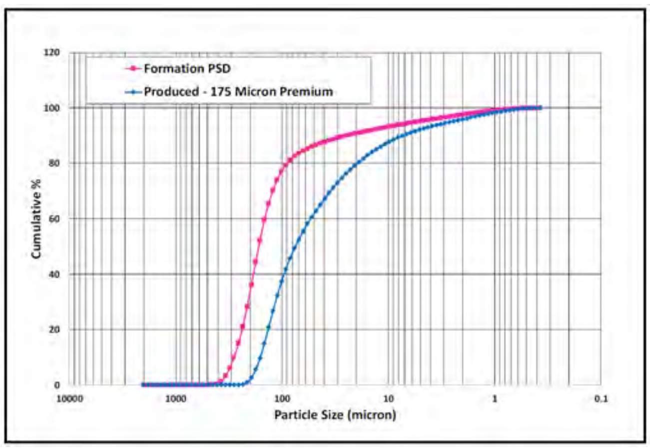

Figure 12—Formation and Produced Particle Size SET Test

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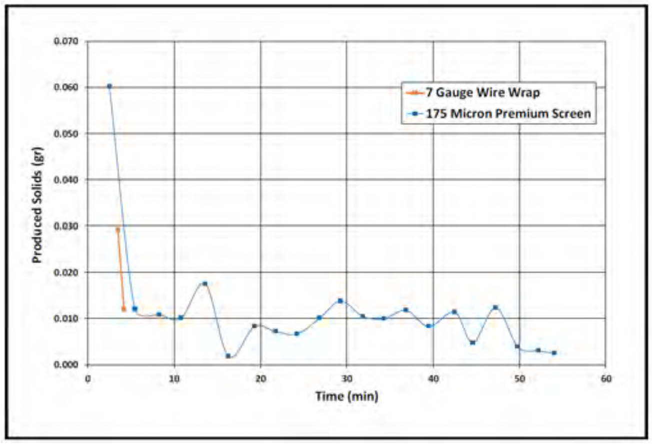

Figure 13—Produced Formation vs. Time SET Test

Permeability Data

All test methods except for the Screen Efficiency Test method provide retained screen permeability data, as shown in Tables 4 & 5. The initial and final permeability of the screens are measured using a viscous Newtonian fluid and calculated using Darcy's Law, shown as Equation 1. The initial permeability of the screen is measured as tested, meaning complete with all components or screen only. At the conclusion of the test, multiple final screen permeability measurements may be performed. First, the formation is removed from the top of the shroud or screen and the permeability is measured. If necessary, the shroud is removed along with any formation trapped between the shroud and screen. The final screen permeability is then measured again. The retained screen permeability is calculated using the final screen permeability after the shroud is removed. In most cases, the permeability of the screen with the shroud in place is lower than the final permeability after the shroud is removed. This is due to the formation sand trapped between the shroud and the screen. The retained permeability data from all available screens is presented in Table 5. All test screens had final permeabilities greater than 50% retained, except for the 175-micron premium screen from the Constant Drawdown method, resulting in a 30% retained permeability. The 50% threshold is used as the standard for gauging if the retained screen permeability is sufficient for field use, as discussed further in the results discussion (Hodge, 2002).

Equation 1: Darcy's Law

$$K(md) = \frac{\mu L\, Q}{\Delta P\, A} * 1000$$

Where:
K = Permeability (md)
μ = Viscosity (cP)
L = Length (cm)
Q = Flow rate (cc/sec)
ΔP = Pressure drop (atmospheres)
A = Area (cm^2)

Additionally, the formation and system permeabilities are determined in the Constant Drawdown and Cyclical Brine test methods. The system permeability is determined directly from the test data, as a position transducer monitors the formation pack length throughout the test. The length of the screen is measured before the test begins. So, the total length used for the system permeability is formation + screen. Once the system permeability is determined, the formation permeability is calculated in a similar manner. The length used is the measured formation length rather than formation + screen as indicated above.

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In the Constant Drawdown test method, drawdown pressure is set at a constant 200 psi nominally with pressure and flow rate continually monitored. The permeability of the formation plus screen and formation only is determined at three stress levels. As the applied stress changes so does the permeability and is presented as Permeability versus Stress in Figures 14 & 15. The figures show the system and formation permeability for the premium and wire wrap screens using the Constant Drawdown test method. The difference in formation permeability is driven by solids production. The 175 premium mesh screen produced more solids than the equivalent wire wrap, resulting in a higher formation and system permeability.

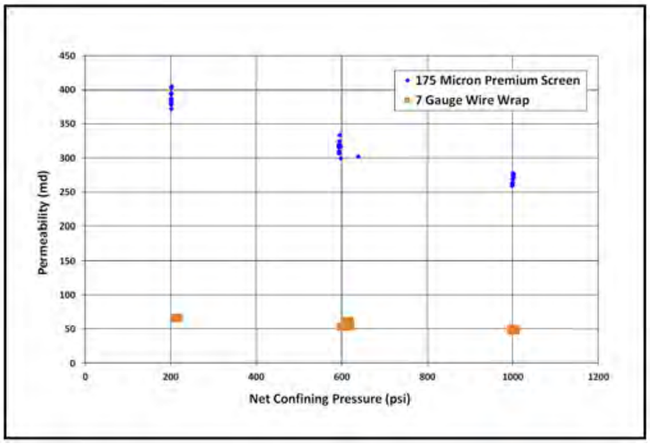

Figure 14—System Permeability versus Confining Stress Constant Drawdown

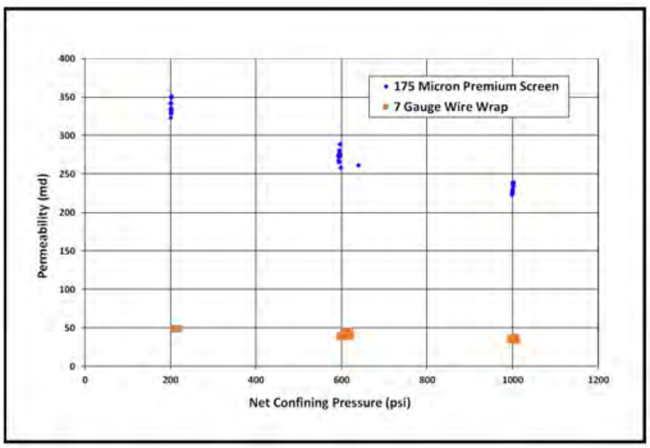

Figure 15—Formation Permeability versus Confining Stress Constant Drawdown

For the Cyclical Brine test, a constant drawdown pressure of 10 psi was applied, and the pressure continually monitored throughout the entire test. After the initial drawdown, the permeability of the formation plus screen was determined at 700-psi net stress for both the production and injection directions. In production direction, the formation particles are challenging the test screen, which results in possible sand production that is dependent upon the formation bridging characteristics. As the flow direction is changed, formation particle migration is observable under the applied 700-psi net stress. Throughout the flow direction cycles, the permeability can change as sand production and sorting occurs, as shown in Figure 16.

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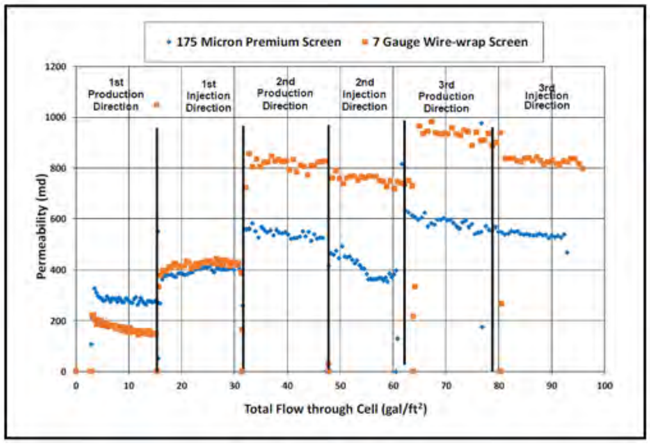

Figure 16—Permeability in Production and Injection Directions Cyclical Brine

Flow Capacity Changes with Volume

In the Constant Drawdown and Cyclical Brine method, the fluid flow rate through the formation and sand control device is driven by the constant drawdown pressure and flow capacity of the system. This means as the flow capacity changes the flow rate will subsequently change (Hodge, 2002). During the initial stage of the Constant Drawdown method, where the rapid collapse of formation onto the sand control device occurs, the flow rate through the system is monitored. This monitored flow rate data measures the changes in flow capacity as the formation collapses and is produced through the screen, as shown in Figure 17.

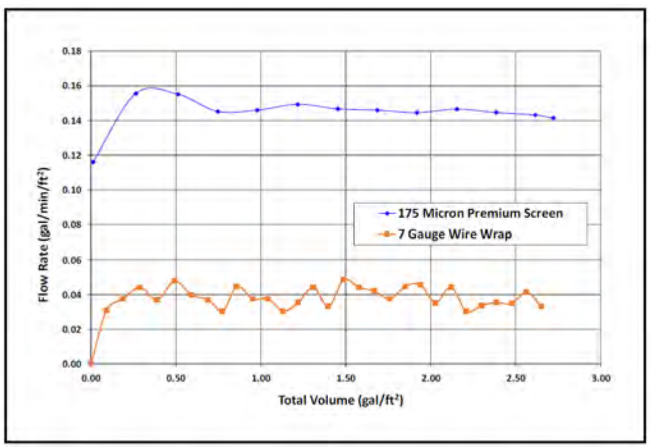

Figure 17—Flow Rate vs. Total Flow Plot for Constant Drawdown Tests

Conversely, in the Constant Rate and Screen Efficiency Test methods, the pressure is subject to change, as the flow rate is held constant. This results in rising pressure as the formation is deposited on the test media by the slurry stream. This change in pressure is continually monitored throughout the test and plotted as pressure versus volume, shown in Figures 18 & 19. By plotting the pressure increase throughout the test, the change in flow capacity can be measured as the formation bridges on the sand control device.

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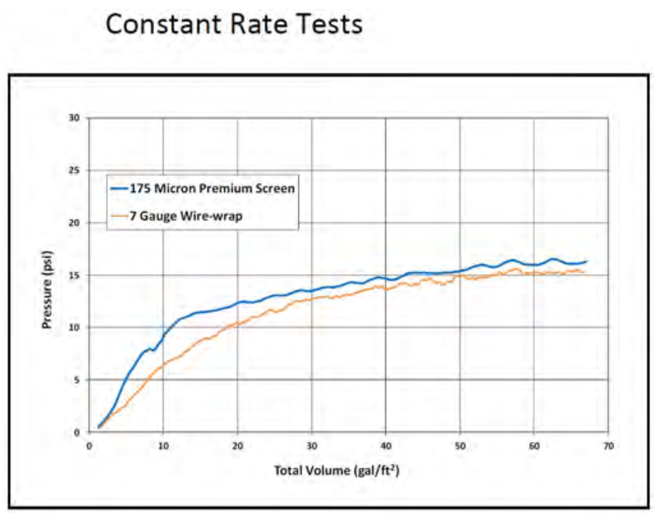

Figure 18—Pressure vs. Volume Plot

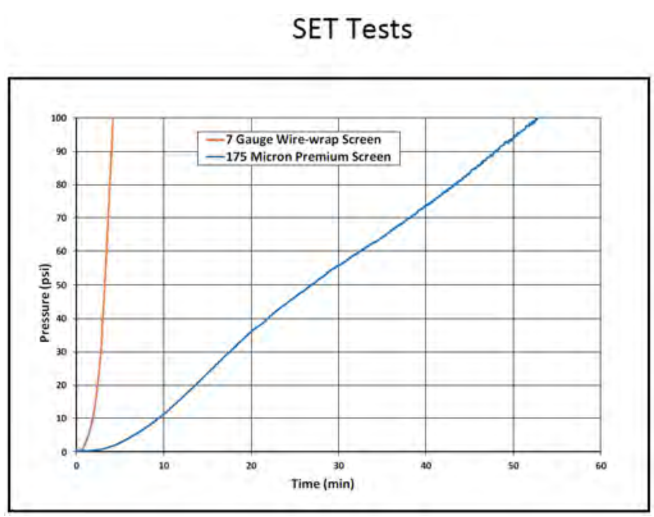

Figure 19—Pressure vs. Time

Data Analysis:

As shown below in Table 5, each of the test methods provide a combination of sand control performance data, which is used to determine if the selected sand control device will be successful for a given completion. For all test methods, the total produced solids and the size of the solids are measured for both test screens. These parameters are the only data points shared between the four test methods. The 175-micron premium mesh screens produced the larger range of total solids between the two screens, with a defined range of 0.004 – 0.11 lb/ft^2. The 7-gauge wire wraps had a total produced solids range of 0.019 – 0.048 lb/ft^2, roughly producing half the amount of the premium mesh screen. The Constant Rate method was the only outlier for this testing series, where the 7-gauge wire wrap produced more solids than the premium screen in the first and second sampling points. The high initial solids production of the 7-gauge wire wrap quickly bridged, resulting in a steep drop in solids production for the remainder of the test, as shown in Figure 10.

It should be noted that the 7-gauge wire wrap total produced solids for the Screen Efficiency Test is significantly lower than the equivalent premium mesh, due to the large disparity in the quantity of solids and volume challenged against the screen. This large extreme spread in the Screen Efficiency Test is a result of the pressure constraints of the test procedure and cell. Additionally, the slurry test methods resulted in lower total produced solids, when compared to the pre-packed rapid collapse test methods. To collect the most

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accurate laboratory data for field comparison the formation failure type should be matched in the laboratory testing method, as shown in Table 5. In this testing series, both screens sufficiently controlled the production of the solids for all test methods. However, when a screen and formation combination is closer to the failure point that is, where the screen is only marginally controlling solids production, the type of test method can make an impact on whether the screen passes the standards for recommendation.

In addition to the total produced solids, the size of the produced solids was measured, when sufficient amounts of formation sample were produced through the screen. Similar to the amount of total produced solids, the 175-micron premium mesh screen produced the larger particles ranging from, 29 – 161 microns. The equivalent 7-gauge wire wrap produced solids in a tighter range of 30 – 72 microns, as shown in Table 5. For two of the eight tests, the production of the solids was insufficient to allow for the measurement of the particle size for the produced solids.

For all test methods except the Screen Efficiency Test, screen permeability data is provided by taking an initial and final permeability measurement and calculating the percent retained. In the case of this study, the formation and screen combinations displayed similar retained screen permeability, except for the 175-micron premium mesh screen in the Constant Drawdown test method. Along with screen permeability, system and formation permeability data is provided in the pre-packed test methods as the formation and screen length are measured variables.

For the slurry test methods, flow capacity data is provided as the pressure changes. In the Constant Rate test method, the maximum pressure for both screens is similar with a maximum pressure of roughly 16 psi at 200 mL/min, with a 1 cp brine solution. However, for the Screen Efficiency Test, the system pressure quickly elevated to 100 psi for the 7-gauge wire wrap, while the 175-micron premium mesh screen reached 100 psi nearly at the 1-hour boundary condition of the testing procedure. The Screen Efficiency Tests were performed at 200 mL/min with a solids concentration of 0.5 g/L using a 34-cp glycol solution.

Table 5—Overall Test Results

Test Method	Screen	Total Produced Solids	Size of Produced Solids	% Retained Screen Permeability	System Permeability (Formation + Screen) (md)	Maximum Pressure (psi)	Time to 100 psi (min)
CDD	175 Micron Premium	0.11	29	30	263	--	--
CDD	175 Micron WW	0.045	30	59	46	--	--
CR	175 Micron Premium	0.004	Not Enough Produced	56	--	16.4	--
CR	175 Micron WW	0.019	72	66	--	15.8	--
SET	175 Micron Premium	0.079	161	--	--	--	55
SET	175 Micron WW	0.014	Not Enough Produced	--	--	--	4
Cyclical Brine	175 Micron Premium	0.083	122	56	570	--	--
Cyclical Brine	175 Micron WW	0.048	36	68	900	--	--

By using the provided laboratory performance data from the test methods above, engineers can make data driven screen selections during well design. By evaluating multiple performance factors and laboratory standards the risk of selecting a sand control device that will be ineffective in controlling solids production is significantly decreased.

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By analyzing the screen performance in the laboratory to the screens installed in the field, Hodge found that the successful screen installments produced < 0.12 lb/ft^2 in the laboratory testing (Hodge, 2002). This was later updated by Adams and Hodge to < 0.15 lb/ft^2 (Adams, 2009). For heavy oil applications, the allowable produced solids are higher at 0.2 lb/ft^2. While this was initially determined using the Constant Drawdown method it has been found that < 0.15 lb/ft^2 of solids production translates well across different test methodologies with exception of the Screen Efficiency Test method.

Hodge also established a retained screen permeability standard of > 50%, which was determined in the same comparative study between laboratory testing to field success. For well production, generally, the higher the retained permeability the higher the well production efficiency. At 50% retained permeability, this is still orders of magnitude higher than the surrounding formation sand permeability (Hodge, 2002). It should be noted that the retained test media permeability gives an overall permeability of the test media. Meaning that the retained permeability does not consider nonuniform damage across the test media. Damage localized to particular spots of the screen, can result in the potential for "hot spots" located in the undamaged areas of the test media. Additional damage to the screen or gravel pack and screen can also occur from the presence of a drill-in filtercake, as demonstrated in Constien (2008). For standard laboratory sand retention testing procedures, a best-case scenario is used, where the tests are conducted with clean sand.

Master curves

Constien and Skidmore, developed a method of predicting sand control performance by creating master curves, which are based on the sand control device pore size and the effective formation size, a ratio defined as d50/UC (2006). To develop a master curve for a specific sand control media, performance data including produced solids, retained permeability, and size of produced solids are ratioed against the effective formation size divided by the pore opening size of the sand control media. Once the initial master curve for a specific sand control media is established, it can be further improved as additional data is collected. By developing an accurate master curve, sand control performance metrics can be predicted for a wide variety of formation particle size distributions found in the completion. This is beneficial during the screen selection process as sand control options can be eliminated with less required laboratory testing, thus lowering testing costs. While master curves were originally designed for the Constant Drawdown method, they are also applicable for all test methods as shown in Figures 20 - 23.

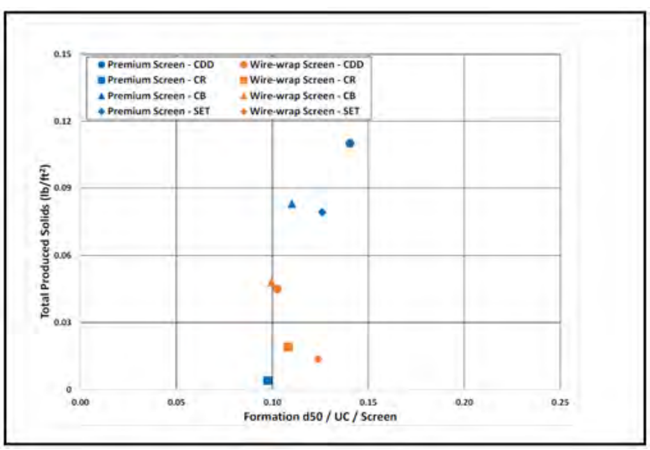

Figure 20—Total Produced Solids

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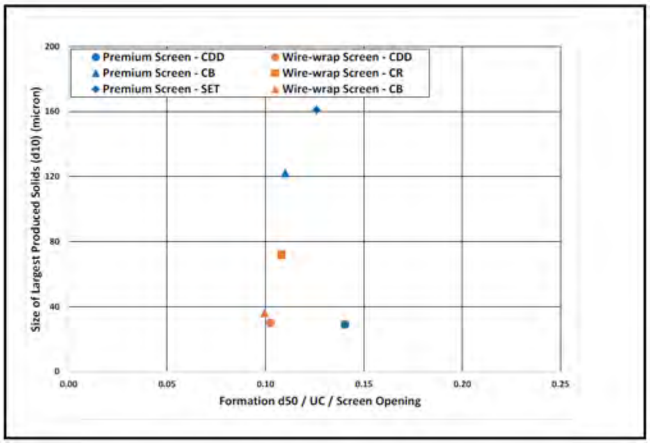

Figure 21—Size of Largest Produced Solids

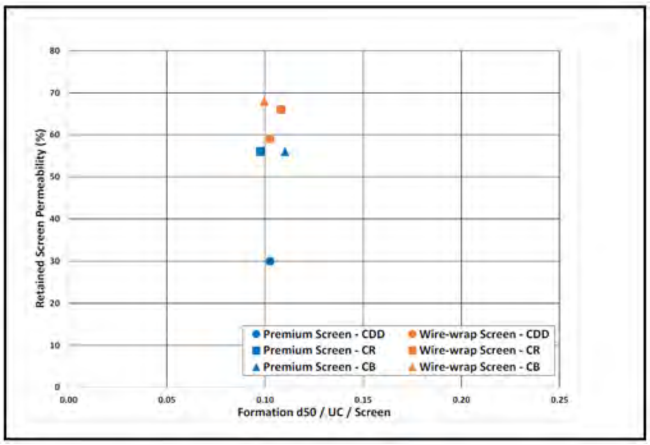

Figure 22—Retained Screen Permeability

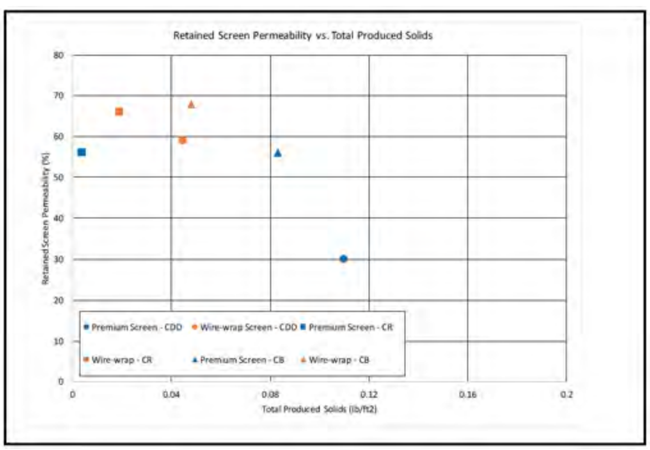

Figure 23—Retained Screen Permeability vs. Total Produced Solids

The mastercurves provided in Figures 20–23 utilize only the tests performed in Table 5. These mastercurves serve to highlight the comparison between the various testing methods. However, due to the testing criteria, the predictive value is limited, as only a single formation distribution was tested against the screens. Additionally, while two different screens were tested, the micron opening size of the screens was the same. Figure 20 shows the total produced solids for each completed test. Except for the Constant Rate test method, the 175-micron premium screen produced more solids than the equivalent 7-gauge wire wrap

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screen. All tests produced solids below the maximum recommended level of 0.15 lb/ft^2. For both screens, the pre-packed test methods, that is the Constant Drawdown and Cyclical Brine produced solids in higher quantities when compared to the slurry test methods.

Figure 21 provides the data for the size of the largest produced solids, expressed as the d10 of the measured micron size. Two of the tests in the series did not have sufficient produced solids for particle size measurement. The Constant Drawdown test method produced the smallest solids for both test screens. The largest solids were produced with the 175-micron premium screen in the Screen Efficiency Test method.

Figure 22 shows the retained screen permeability data for each test, with exception of the Screen Efficiency Tests. All of the tests had retained screen permeabilities between 56-68%, with the Constant Drawdown 175-micron premium screen being the exception at 30%. An additional correlation has been provided in Figure 23, which serves to explain the lower retained permeability for the aforementioned data. Figure 23 shows the retained screen permeability versus total produced solids. The curve shows a trend to lower retained screen permeability with increasing solids production. The premium screen used in the Constant Drawdown method has the highest produced solids in the series and thus the lowest retained screen permeability. This inverse relationship between retained permeability and produced solids is often typical for sand retention testing.

Figures 24–26 show the mastercurves from SPE189515 with additional data from the Cyclical Brine and Screen Efficiency Test methods (Fischer, 2018). Although there were differences in performance results between the various methods, shown in the previous set of mastercurves, when plotted with the more extensive SPE189515 data set, the data from the Cyclical Brine and Screen Efficiency Test falls on the same trend line with the Constant Drawdown and Constant Rate data.

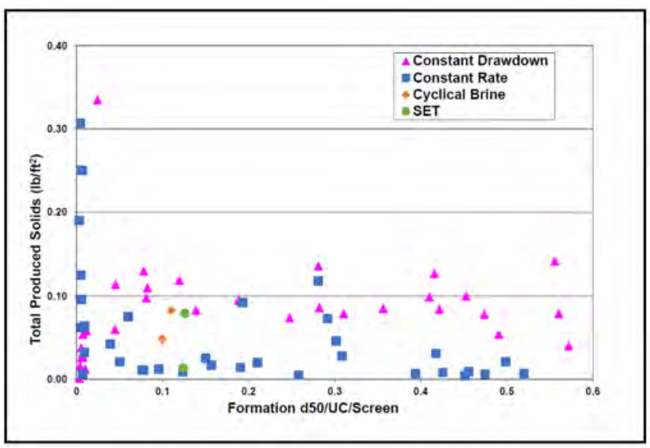

Figure 24—Total Produced Solids

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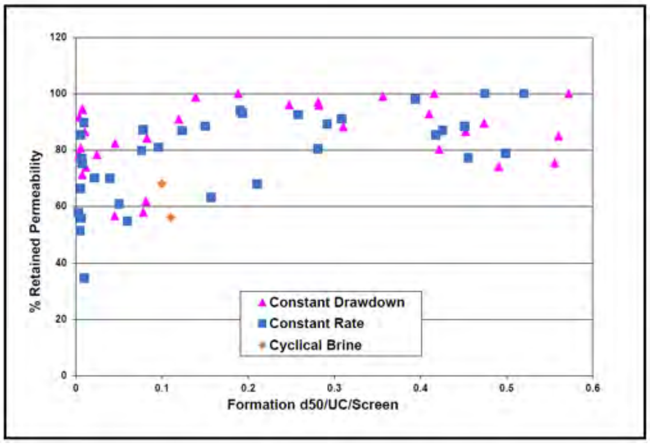

Figure 25—Retained Screen Permeability

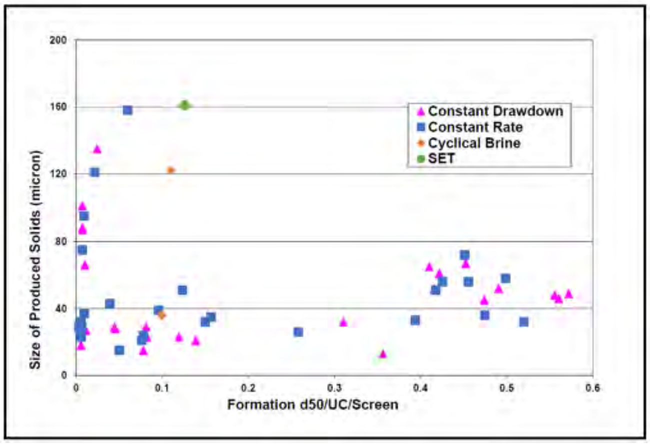

Figure 26—Size of Produced Solids

Conclusions:

1. An analysis of the formation particle size data must be conducted in order to select the formations for sand retention testing and should represent the entirety of the sand distributions found in the target completion.
2. After the potential for wellbore instability and the need for a sand control device is established, the laboratory testing method which closely simulates the predicted formation failure should be utilized for the most accurate results.
3. For cases where the formation and wellbore instability analysis is limited, the Constant Drawdown testing method is recommended due to the quantity of data provided when compared to other test methods.
4. By utilizing mastercurves, the performance of sand retention devices can be predicted for a variety of formation particle size distributions down the lateral, where the predictive accuracy improves as additional data is added

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