Development of a Sand Retention Test Set-Up Focusing on the Measurement of Produced Sand

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Abstract

The successful operation of sand screens depends on many parameters, including geology, wellbore conditions, installation and bean up. To understand the interaction of the different influential factors with various screens, laboratory investigations can be conducted. These investigations are called Sand Retention Tests (SRT). There are no standardized set-ups or procedures for SRTs, instead different approaches exist to simulate different processes. This article will give an introduction into the development of such an experimental set-up and presents a novel method to determine the amount of produced sand during the test.

Sand retention tests aim to answer two questions:

1) *Is the screen able to retain the mobilized formation particles? and*
2) *How big is the influence on the productivity of the well?*

During sand retention tests a fluid is pumped through a screen sample and a bed of particles. The particles that are transported through the sample, and the pressure drop across screen and retained sand are all measured. Multiple approaches have been proposed to let the particles interact with the screen in different ways.

This newly developed set-up uses flat screen samples. Two methods have been developed to let the particles interact with the screen sample: prepacked and slurry tests. In prepacked tests the particles are placed on top of the screen sample before the flow is started. In slurry tests the particles can be injected into the fluid flow to be transported to the bare screen. The pressure differential is continuously measured. The produced particles are collected below the screen sample on a paper filter. The paper can be incinerated up to 99.99% without leaving ash behind. This allows determination of the mass of produced sand by simple differential weighing.

The measurements that can be conducted with the set-up can be used to answer the relevant questions of SRTs. A modular set-up enables the replication of various wellbore and production conditions. The proposed method of determining the mass of sand is a novel approach. Its advantage is that it yields a high accuracy due to the complete collection of particles and a precise weighing technique.

Introduction

Sand production is a major challenge in many oil, gas and geothermal wells. The term summarizes the mobilization, transport and deposition of formation solids due to the production of reservoir fluids. It can cause a wide variety of problems such as blockages of inflow area or surface pipelines and erosion of downhole equipment. Particles that are produced to the surface have to be separated and properly disposed. A wide variety of operational procedures and completion elements have been developed to counteract sand production and the consequences that are associated with it.

One of the most popular options is the installation of a sand screen in front of the productive formation (Fig. 1). The screen can be installed alone (standalone screen) or as part of a gravel pack (gravel pack screen). In the case of a gravel pack, the mobilized formation solids are retained by the artificial sand pack in the annulus directly at the face of the wellbore. The gravel is usually sized to be 5–6 times larger than the D50 of the formation particles (Saucier-Criterion [1]). The screen openings are chosen smaller than the gravel to retain it in the annulus. This design is proven to work successfully under many operational conditions and is accepted within the industry [2].

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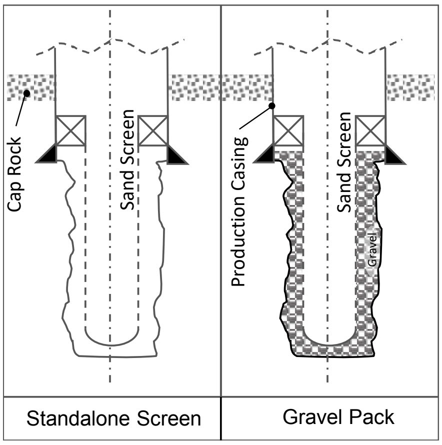


Fig. 1 Sand screen installation in open-hole wells – Schematic

Unlike gravel packs, standalone screens are designed to retain mobilized particles in the annulus. The goal is to create a permeable layer of retained particles, which acts like a gravel pack. The sizing of screen openings has been discussed for more than a century and due to the many influential parameters on the sand control process, consensus is yet to be achieved. Initially, screens were only used to stabilize the wellbore and prevent it from collapsing. The openings were chosen large enough to allow the passage of all particles. This approach used the benefit of increased near wellbore porosity on the production of fluids [3]. It was later discovered, that a permeable layer could be created. This led to the definition of the important reservoir conditions, fluid properties and operational procedures, that have to be considered when using what was later called a standalone screen [4]. However, it was not until 1937, that the mechanisms of sand control were clearly identified by Coberly [5] after conducting laboratory investigations (Fig. 2). He found out, that particles form bridges over rectangular screen openings (i.e. slots) when the width of the slot is not more than twice their diameter. Coberly proposed the first design criterion (screen opening equal to twice the D90, i.e. largest 10%, of formation solids particle size distribution), but was immediately challenged by Wilson [6]. Wilson proposed that the screen opening should be equal to the D90 of the formation solids. The criterion is nowadays referred to as the Gulf Coast Criterion.

Today the limits of standalone screens are much broader and more refined [7]. Some typical criteria for exclusion remain bi-modal particle size distributions, very fine sands and variations within the formation. Different sizing criteria have been proposed for different screen types (i.e. mesh screens, wire wrapped screens). An excellent review of the selection of standalone screens has been given by Chanpura et. al. [8]. The article discusses the application of standalone screens vs. gravel packs, but also the sizing of the screens.

Standalone screens should be sized based on formation characteristics (especially particle size distribution), experience from the same or comparable fields and operational conditions. Due to the sand control mechanism of the screens, some particles have to be produced through the screen. If there are limits to this initial (and temporarily occurring) sand production, it has to be taken into account. The vast number of influential factors on the sand control process make it impossible to clearly predict the behavior of a sand screen.

This is where laboratory investigations come into play. The investigation of the interaction of particles and screens in small scale experiments is called sand retention testing. The experiments are conducted to answer two questions:

1) Is the screen able to retain the mobilized particles in the annulus at different operating conditions?
2) How big is the influence of the installation of the sand screen on the productivity of the well?

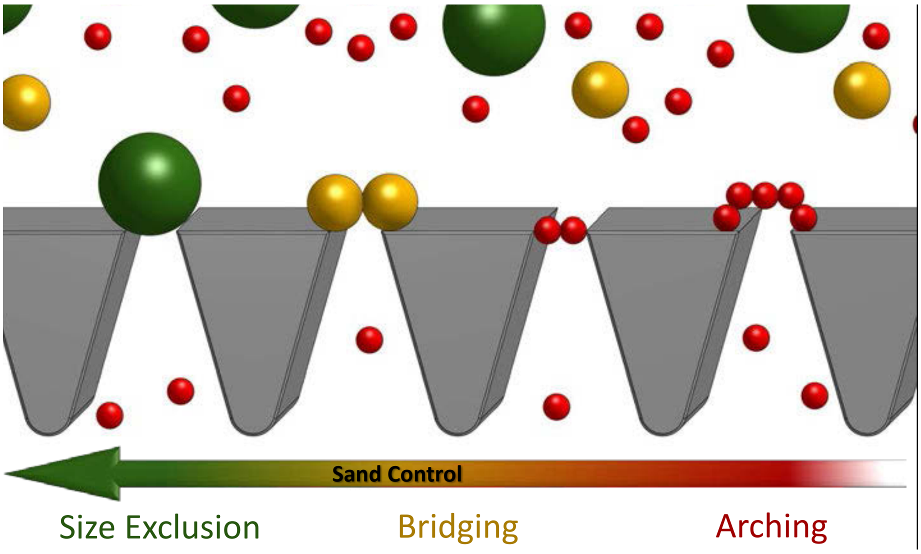


Fig. 2 Particle retention mechanisms on the surface of wire wrapped screens

The questions can be further refined. For example, how much sand is produced through the screen before sand control is achieved? Which size do the produced particles have? Which permeability is the sand pack expected to have?

To answer these questions, a set-up for sand retention tests was developed. The main focus during the development was the measurement of the produced sand. Initially, the set-up was built to compare a newly developed ceramic coated screen to mesh and wire wrapped screens[9, 10]. Over the span of two years, various components of the set-up were designed, further improved and numerous experiments conducted. This article gives an overview of the development stages of a set up for this type of investigation and describes the experimental procedures for slurry and prepacked tests. The results of a comparative prepacked test series with different sand measurement techniques are discussed.

Literature review and preliminary thoughts

Sand retention tests are used for the correct selection and design of standalone screens. Two types of tests have to be distinguished: slurry tests and prepacked tests. They are designed to replicate different wellbore conditions. In a slurry test, a suspension is pumped through a screen sample. The particles are gradually retained by the screen until a stable sand pack develops that retains all particles. In a prepacked test, the sand pack already lies on the screen before the fluid flow is started. Therefore, slurry tests correspond to the production of single particles in low concentration, e.g. in cased holes and consolidated formations. Prepacked tests are comparable to the conditions in open holes in unconsolidated conditions, where the wellbore collapses around the screen shortly after the production is started.

During the test three types of measurements are taken, namely the pressure drop across the sand pack and screen sample, the flow rate and the mass of produced sand. The measurements correlate with the fundamental questions of sand retention tests. The pressure drop and flow rate are used to determine the influence on the productivity. The amount of produced sand gives an indication of the sand retention capability of the screen under the given conditions. There is no standardized procedure for sand retention tests. Instead a number of different set-ups were developed that are able to deliver the desired measurements.

Fundamental structure of sand retention test set ups

All described set-ups are equipped with a pump, which delivers a constant flow without significant fluctuations in rate or pressure. A test cell is used to mount the screen samples and includes a defined space for the retained particles. The fluid is collected behind the cell. One or more pressure sensors can be mounted within the cell or the connecting flow lines to measure the pressure drop across the screen sample and sand pack.

Test cells

There are different concepts for test cells. They are distinguished by the geometry of the screen sample and retained sand pack. The screen samples can either be flat or curved. Curved segments are closer to the in-situ geometry of screens. They can be combined with a funnel-like space for the sand to replicate radial inflow. A simpler shape can be used for flat samples. Here a cylindrical space above the screens enables the calculation of the sand pack permeability. Some cells are designed to apply a confining pressure on the sand pack [11].

Measurement of produced sand

The mass of the produced sand can be determined in a number of different ways. Particles that are transported through the screen sample have to be collected and weighed. Proposed methods include inline sand separators [12], filtration with paper filters [13], collection of the suspension and later separation [14] by decantation, evaporation [15] and filtration [2, 16]. If the produced fluid is collected in multiple batches [7], the measured concentrations can be correlated with the time of sand production. This allows making statements on the beginning, stabilization and end of sand production.

Slurry injector

Set-ups for slurry tests either need a pump that is resistant to solids or an assembly to inject solids into a main flow. The experiments are usually carried out at a constant flow rate with a solids concentration of less than one percent. The differential pressure is constantly monitored [17]. Ballard and Beare [18] suggested a viscosified carrier fluid (usually a polymer-solution) to inject the particles into a main flow. Due to the small amount of injected fluid, the polymer is diluted to a negligible concentration. When using a solids-tolerant pump, the slurry is prepared in a tank and constantly stirred to prevent sedimentation.

A second injection set-up was proposed by Fischer and Hamby [14]. Instead of diluting the particles in a viscosified slurry, the particles are injected as a highly concentrated mud. The mud is created by saturating the pores of the sand until an injectable consistency is achieved.

A mixture between slurry and prepacked tests was conducted by Hodge et. al. [7]. They started with a bare screen sample and injected a concentrated sand pack into the cell. This sand pack instantly acted like a prepacked sand bed.

Significant findings of previous publications

Sand retention tests are used both in fundamental research and practical application. A practical question would be as follows: which type of filter and which opening size can provide sand control under given wellbore and reservoir conditions? More fundamental research aims to answer questions such as, which opening size of a defined filter provides the best sand control under varying conditions? Different influential factors have to be considered, depending on the type of research. Mahmoudi et. al. [19] state a number of factors that have an influence on the outcome of an SRT. These include particle size distribution, porosity, particle shape and surface properties of the particles such as wettability and roughness. Gillespie et. al. [15] confirmed the influence of the particle size distribution and claimed that different distributions can have a significant influence on the results if the same screen sample is used. This knowledge is essential to derive design guidelines based on experimental data. Further influential parameters are the type of fluid and the flow rates that are used during the tests. The latter are usually much higher in the laboratory when compared to the flow area of the screen in the field [16]. To keep the experimental conditions as close to in-situ as possible, particles from drilled reservoir cores should be used. Artificial particle mixtures always deviate in wettability, size and shape and therefore inevitably deliver diverging results. [20]

The sand control process during a successful slurry test can be described as follows[15]: During the first phase a thin filter cake consisting of retained particles forms. After that further particles are retained and the filter cake stabilizes the early particle bridges. The amount of sand production ceases. Once a few layers of retained particles have formed, the pressure rises proportional to the height of the filter cake. If sand control is not achieved, the concentration of the produced particles will be equal to the injected concentration [7]. This can be determined by a continuous or stepwise measurement of the sand production.

When conducting prepacked tests, it is possible, that some sand control is already achieved during the assembly of the sand pack on the screen sample. Some particles will bridge over the screen openings or fall through the sample before the flow is started. After starting the flow, further bridging or size exclusion occurs until full sand control is in place similar to slurry testing.

Ballard and Beare [20] found out, that more sand is produced during slurry testing, when compared to prepacked tests under otherwise similar conditions. However, both procedures are appropriate to compare different samples. There was no evidence that the different set-ups led to different design criteria. What they were able to determine was, that particles that are larger than the screen openings are mainly responsible for achieving successful sand control.

Sand retention tests have been used extensively to disprove, prove, verify and expand the design and selection guideline of standalone screens. Markestat et. al. [12] proposed that Coberly [5] underestimates the risk of sand production, while the gulf coast criterion [6] can both over- and underestimate sand production depending on the particle size distribution. This means, that the whole distribution should be used for the design of a screen instead of a single parameter. Instead of proposing a single suitable slot width, they suggested defining a range of sizes. This approach can be used to find a screen for formations with small variations in particle size. They also used their testing to verify that a slow bean up reduces the risk of plugging.

On the contrary, Chanpura et. al. [17] claimed that plugging is very difficult to quantify from a sand retention test, when clean formation sand is used (i.e. without mud solids or mixing of particles from different layers). They were able to conduct successful tests with very poorly sorted distributions and deducted that standalone screens can be used under a wide variety of conditions. However, similar to other authors they were able to easily verify successful sand control in their tests and could therefore derive appropriate (i.e. maximum) screen openings.

As stated earlier, slurry and prepacked tests aim to recreate different wellbore conditions. These conditions lead to different demands on the screens. Some authors ascribe one of the two tests a higher difficulty. It is obvious that such statements are not target-oriented, when sand retention tests are conducted with the previously mentioned goals in mind. This subject was well discussed by Chanpura et. al. [21] , who start their paper up with the “industry wisdom” of a slurry test being more challenging. A corresponding statement to be the “worst-case-scenario” can also be found for prepacked tests [12].

The tests should be conducted with the knowledge that wellbore conditions (especially the transport mechanism of the particles to the screen) can never be fully replicated and even small variations in set-up and execution can have significant influence on the results. It is therefore important to reproduce tests and not frivolously interpret the measured data. Single measurements can be influenced by small errors and it is more important to look at trends [16]. This also means that the results of SRTs can never be directly related to wellbore conditions [20].

It is important to define boundary values before the tests. A comparative evaluation (e.g. choosing the screen that produced the least amount of sand) can lead to unacceptable results in the real world [8]. Instead the sand production should be expressed as a

Fig. 3 High pressure SRT-Set-up

Tab. 1 Technical Data of the set-up

Pump	Knauer BlueShadow 80P with 500 ml Titanium-Pump-Head
Flow Rate	1 ml/min to 500 ml/min
Max. Pressure	100 bar (limited by cell)
SRT-Types	Prepacked and Slurry Tests
Fluid	Water

specific value, such as produced mass per screen-inflow-area (kg/m^2) and the measured permeability of the sand pack should be compared to the reservoir permeability. Hodge et. al. [7] propose a specific sand production of 5 kg/m^2 and permeability of at least 50–80% of the unaltered reservoir permeability.

The set-up

The set-up was planned to be modular. This meant, that all components could be developed independently and are easily exchangeable. All components are mounted in an aluminum frame (WxHxL 140x70x240 cm, Fig. 3). The front can be closed by four transparent doors. The back, sides and roof are covered by polycarbonate sheets. An aluminum trough at the bottom can collect spilled fluids.

Basic design

Initially, the set-up was designed for prepacked-SRTs only. The possibility to conduct slurry tests was added later. A tank is used to store tap water. An HPLC-pump is used to provide the desired flow rate and pressure for the tests. The flow rate can be adjusted between 1 ml/min and 500 ml/min at pressures of up to 100 bars. Two test-cells were designed for the set-up (see Fig. 4 and Fig. 5). The sample geometry is the same for both cells: Flat samples with a diameter of 50 mm are used. 38 mm (1.5 inch) are open to flow. A safety valve is placed between pump and cell to release fluids in case of high pressures. Cell and pipes can be vented through a blind plug at the top. The water that is pumped during the test is collected at an outlet below the cell.

Test cell 1 (stainless steel, high pressure)

The first cell is made of stainless steel and can withstand pressures of up to 50 bar and temperatures of up to 100°C. These extensive conditions were chosen to enable a later investigation of viscous fluids and the influence of temperature. The cell consists of three parts. The middle is designed to hold the screen samples in a 51 mm hole with a depth of 25 mm. This allows mounting samples with different heights and also base pipes. A hole with a diameter of 38 mm continues all the way through the middle part above the screen sample. The screen samples are held in place by the lower lid using spacer rings. After sand is poured into the upper opening onto the screen, the top lid is closed. The sand bed can have a height of up to 6 cm. The high-pressure cell has three threaded holes for sensors. Two pressure sensors are mounted above and below the sand pack and a temperature sensor is placed above the sand pack. The cell is connected to the pipes of the set-up by ½ inch external threads. Sand that is produced through the sample is transported vertically out of the set-up and collected.

To measure the sand production during the tests with this cell, the particles that are transported out of the set-up by the water are collected in a folded paper filter. The paper is supported by a funnel. The paper is dried after the experiment and weighed. In order to minimize the effect of relative humidity, the weight of the filter paper before and after the experiments is determined directly after drying at 80°C in an oven.

Test cell 2 (transparent, low pressure)

The second cell (Fig. 7) was designed with two goals in mind. First, the accumulation of sand and the behavior of the sand bed should be observable during the experiments. Second, a new way of collecting the produced particles was needed to better quantify the sand production. The first goal was achieved by using a transparent acrylic glass cylinder with a diameter of 90 mm to mount the samples. The cylinder has an internal hole of 38 mm that is enlarged to 51 mm at the bottom to accommodate the samples. The transparent part with samples and spacer rings is then held together by an upper and lower lid that are connected by six rods. The lower lid has a built in in-line filter holder for paper filters. The 50 mm diameter round paper filters are mounted from the bottom and are mechanically supported by a metal mesh. The space above the paper filter has a cylindrical shape with a diameter of 38 mm (equal to the open flow area of the screen sample). This design ensures that the particles that are produced are also transported to the paper filter without obstruction. A ¼ inch threaded hole between screen sample and paper filter is used to mount a pressure sensor on to the side of the lower lid. The mount for the upper pressure sensor was integrated in the piping above the cell. The temperature is measured below the cell. The cell is connected to the piping of the set-up by a ¾ inch internal thread at the top and a ½ inch internal thread at the bottom. The technical data of both cells is listed in Table 2.

To determine the mass of the produced sand, the paper filter is removed from the cell and incinerated in a ceramic crucible. The paper is designed to burn with an ash content of only 0,007%. The weight of the particles can therefore be determined by simple differential weighing of the crucible. The steps to dry the paper are not necessary in comparison to the high-pressure set-up. The accuracy of this method was determined before the tests. Paper filters with defined masses of particles were incinerat-

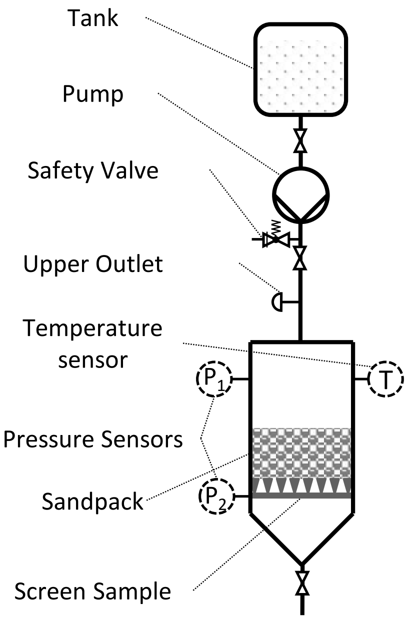


Fig. 4 Early prepacked design featuring the high pressure cell

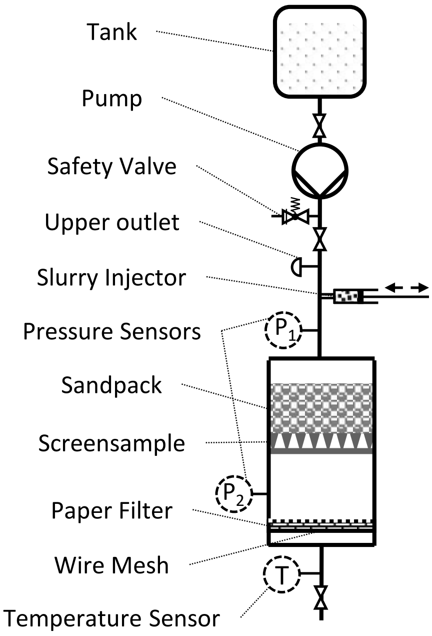
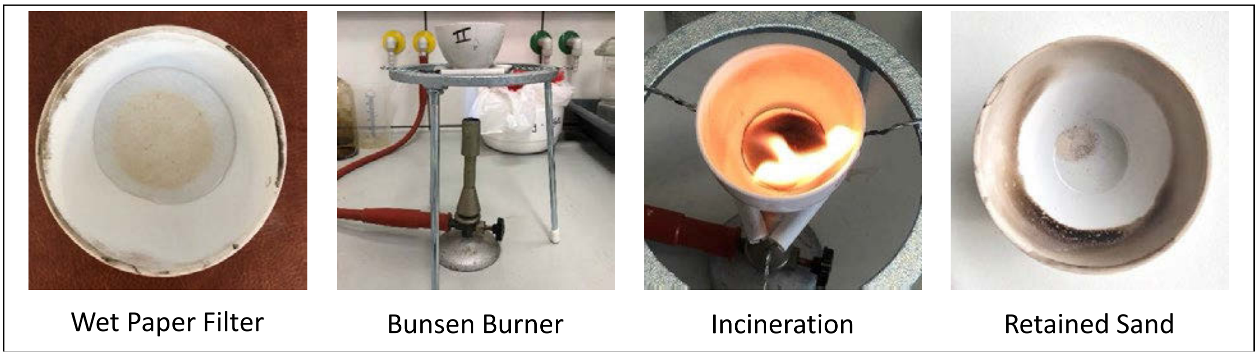


Fig. 5 Slurry-Set-Up featuring the transparent cell



Wet Paper Filter | Bunsen Burner | Incineration | Retained Sand

Fig. 6 Process steps of incineration

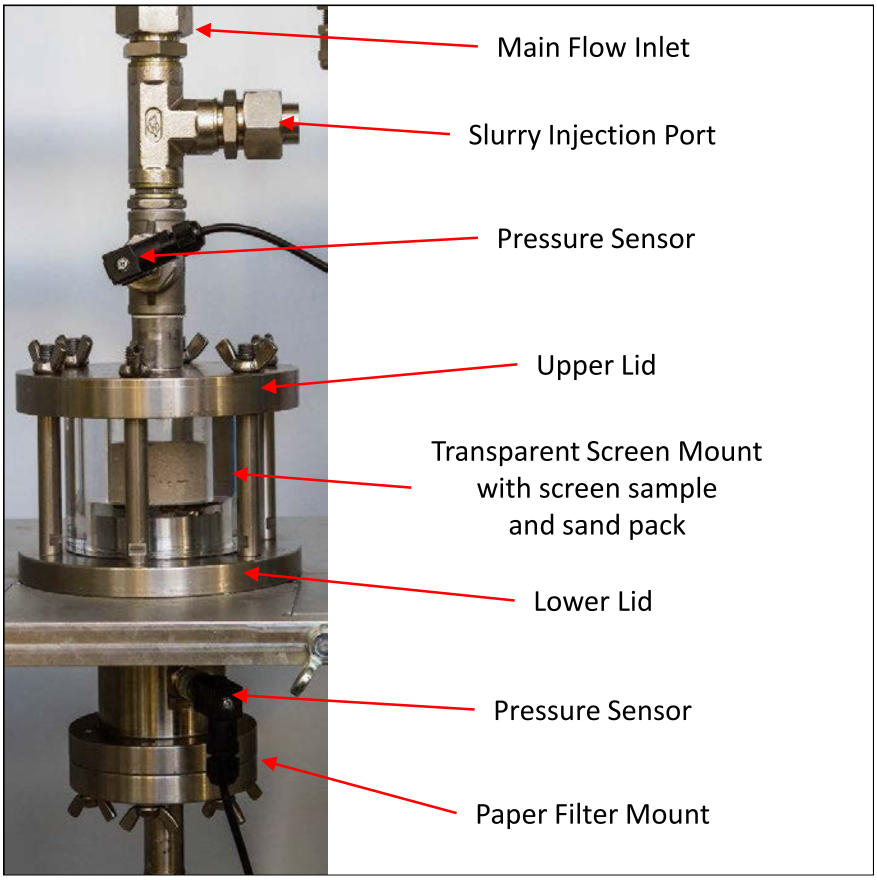


Fig. 7 Transparent SRT-Cell

Tab. 2 Technical Data of the cells

Element	Cell 1 (High Pressure)	Cells 2 (Transparent)
Sample Geometry	round, flat (ø50 mm)	
Open Flow Diameter	ø38 mm (1.5 inch)	
Max. Pressure	50 bar	3 bar
Temperature range	5–100 °C	room temperature
Pressure Sensors	10 bar relative pressure	
Temperature sensors	Pt100	
Sand collection	external, folded filter	internal, flat in-line-filter

ed. The average error from ten measurements was less than 1.5%. The steps of the incineration process are shown in Figure 6.

Slurry injector

The design of the slurry injector was inspired by the approach from Fischer and Hamby[14]. It uses a ½ inch pipe to store a mixture of water and particles. The pipe is connected to the set-up via a simple cutting ring fitting. A piston pushes the mud into the main flow. The piston is connected to a threaded bar which can be turned by hand. The bar is held in place by a threaded nut, that is again connected to the pipe via a mounting piece, which can be threaded to one side of the pipe. The dismantled components of the injector are shown in Figure 8.

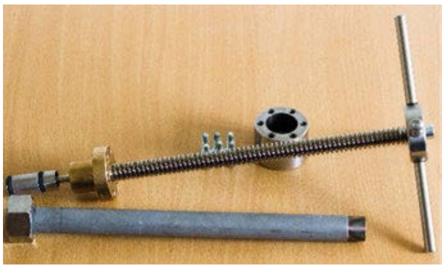


Fig. 8 Slurry Injector (dismantled)

Slurry tests

For slurry tests a screen sample was mounted in the cell and then the set-up was filled with water from the bottom to efficiently displace all of the air. Then the slurry injector with the sand-water mix was mounted and the rest of the air was vented out through the upper opening. All preliminary slurry tests to this date were conducted at a flow rate of 100 ml/min. The particle size distribution of the sand is shown in Figure 9.

The injected particle concentration depended on the rate at which the piston was moved. Figure 10 shows the recorded pressure drop vs. time. A 200 µm screen was used. The discontinuous injection of particles led to a nonlinear correlation between time and pressure. Due to high friction in the injection system, the piston had to be moved backwards several times to surge water into the sand. The test was repeated with a 500 µm sample. This resulted in no measurable pressure drop. Most of the particles were transported through the screen and there was always an uncovered slot-section. Despite obvious room for improvement in particle injection, the feasibility of this slurry test procedure was proven. Further developments will focus on continuous and possibly automated injection of particles.

Prepacked tests

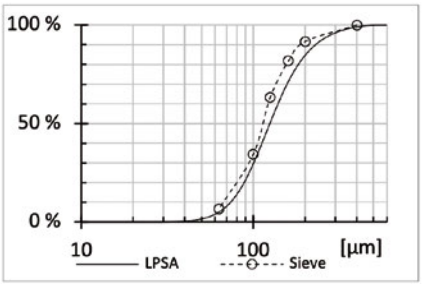


Fig. 9 Particle size distribution of the tested sand

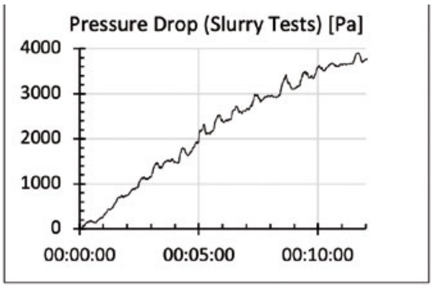


Fig. 10 Pressure drop during Slurry testing

The prepacked tests focused on the measurement of produced sand. The sand production in the high-pressure cell and the transparent cell were compared. 50 g of sand with the same particle size distribution (see Fig. 9) were used for each test. In order to minimize the variations between the tests, all were conducted in the same manner by the same person. First, the sample was mounted in the cell, which was then filled with water to the top of the screen. Then the sand was placed on the sample and carefully soaked with water. This procedure was chosen to minimize particle transport through the sample before the test. The rest of the cell and pipes were filled up with water afterwards. The tests were conducted in five flow rate stages. It was started with a rate of 100 ml/min. Then, the flow was raised to 200 ml/min and 300 ml/min before being reduced in the same steps. Each rate was kept constant for three minutes.

The results of two samples will be discussed in the following passage. These were a wire wrapped screen (WWS) made of V-shaped wires with a width of 3 mm and a metal mesh screen. The mesh sample was assembled by combining five layers. The inner and outer shroud consisted of perforated plates (Rv 5-8). The drainage layer above and below the middle sand control layer included 1 mm plain meshes. The sand control layer was a plain dutch weave coupon. Both samples had a nominal opening size of 200 µm. The measured slot width of the wire wrapped sample was 225 µm. The filter cut point of the mesh screen was not determined. Each sample was tested five times in each cell under the same conditions to further investigate variations between single measurements.

Sand control was established during all tests. Fig. 11 shows the measured mass of particles that was produced during the tests. It can be seen, that the measured masses vary significantly between the five tests of the individual samples. All average masses are within the same order of magnitude. The variations within individual samples can be higher than the variation between average mass of the different samples. The masses that were determined by differential weighing were on average higher than the mass determined by incinerating. It is unknown if this is caused by the test procedure or random variation.

The measured masses were divided by the open area to obtain the specific sand production as proposed by Hodge et. al.[7] (see Fig. 12). The open area of the mesh screen was estimated to be 10%. This is the result of the combination of the open areas of the outer shroud and the sand control screen, neglecting the effect of the drainage layer. The effective open area of a mesh screen cannot be calculated analytically and is therefore a subject of discussion. If the true open area was higher, the specific sand production of the mesh screen would decrease in comparison to the shown diagram. In any case, the specific sand production of the mesh screens is below the proposed value of 5 kg/m^2 of open screen area. The wire wrapped screen produced more sand than the cut off value in some tests and especially when determined by weighing. However, it has to be pointed out, that the specific production is based on open screen area not total screen area. Sand production specific to the total screen area would roughly be one

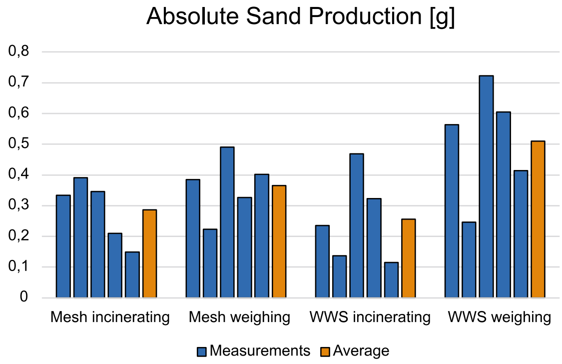


Fig. 11 Absolute mass of produced sand during testing

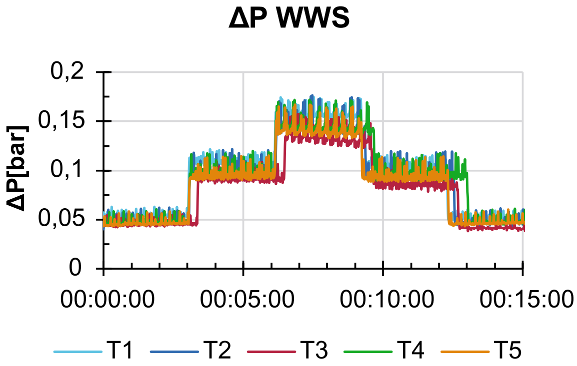


Fig. 13 Pressure Drop (WWS, Prepacked Test, Transparent Cell)

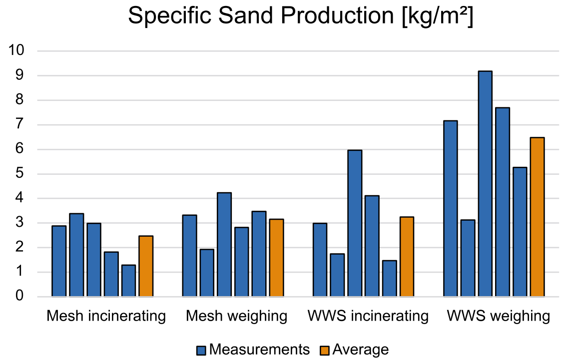


Fig. 12 Calculated specific sand production

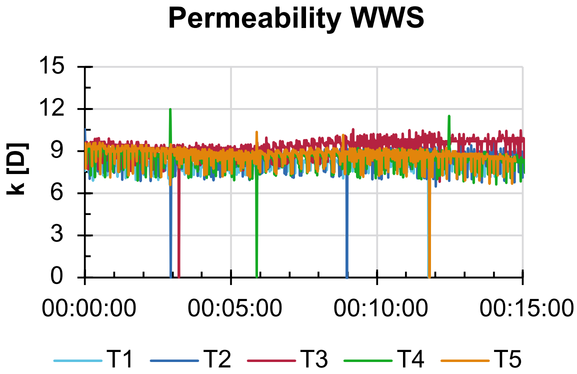


Fig. 14 Calculated Permeability from pressure drops shown in Fig. 13

order of magnitude lower. Assuming the dimension of the screens in-situ are equal, the proportions between the values would stay equal to the absolute sand production.

Fig. 13 exemplarily shows the measured pressure drops of the wire wrapped screen tests in the transparent cell (tests numbered T1 … T5). The pressure drop can be used to calculate the permeability of the sand pack (shown in Fig. 14). Both pressure drop and permeability show no significant variations between the tests. This is true for all twenty tests. Fig. 15 shows the calculated permeability at the end of the test in relation to the produced sand mass. A significant correlation between produced sand and permeability could not be found.

We conclude that the sand production through a given screen sample cannot be determined by a single test due to random variations. This confirms the previously discussed findings from Ballard and Beare[16]. From the conducted testing it was also not possible to find a significant relationship between sand production (neither absolute nor specific) and pressure drop or permeability. We propose that this is due to the small variations in produced sand between the tests and the current accuracy of the pressure measurement. It might be possible to find such a relationship when comparing the results of different screen opening sizes with the same sand, resulting in larger variations of produced sand. It is also possible, that only a small fraction of the sand pack near the screen is affected by the sand production. The mass of produced sand is around 1% of the initial mass of the sand pack. The total pressure drop and therefore the permeability is probably still dominated by the unaltered sand pack above. However, the pressure measurement is not superfluous, as it can be used to quickly identify a sand control failure. Fig. 16 shows the failure of a sand screen due to instantaneous loss of sand control at the start of the flow. It can be seen that a small pressure increase can be detected, before a section of the sample is open to the flow. Fig. 17 shows a sand control failure at a later stage of a prepacked test. The pressure drop increases with the increase in flow rate. The pressure decreases during the individual stages, probably due to continuous but small sand production. Once enough sand is produced and the flow rate is high enough to mobilize many particles, the whole sand pack fails and the pressure drop decreases significantly.

Conclusion and outlook

Sand retention tests are an important tool to evaluate the performance of sand screens during the design and selection stage. The newly developed set-up was successfully used to investigate the sand retention capabilities of different screen samples. Both slurry and prepacked tests can be conducted under a wide range of conditions, including particles, flow rates and pressures. Pressure drop and sand production can be measured. A sand control failure can easily be identified by either of the two measurements. The innovative method of incinerating the paper filter, that collects the produced particles, was successfully implemented and tested in comparison to a traditional measurement. The detected differences between the measurement-methods are negligible. The presented test results show that the established design criteria provide reliable sand control with tolerable initial sand production. Differences in pressure drop (i.e. impacts on the productivity of the well) could not be determined from the presented test series. The repetition of tests under the same conditions shows that random variations in test-results exist. This is in line with previous findings.

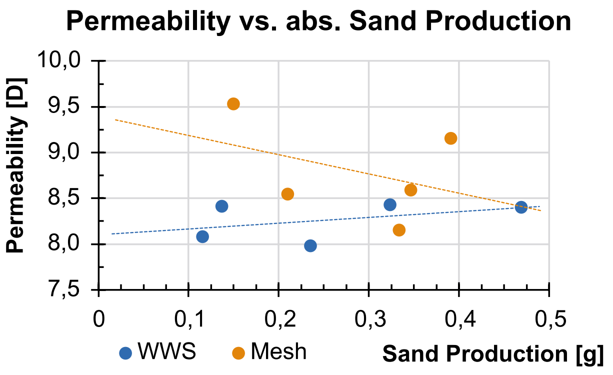


Fig. 15 Correlation between permeability and measured sand production (prepacked test, transparent cell)

The full potential of the set-up has not yet been fully exploited. Experiments involving multiphase flow and viscosity effects are possible. Current limitations of the set-up are the discontinuous slurry injection and the accuracy of the pressure measurement. Both aspects will be improved in the future. This will be combined with further test series for practical applications and fundamental research.

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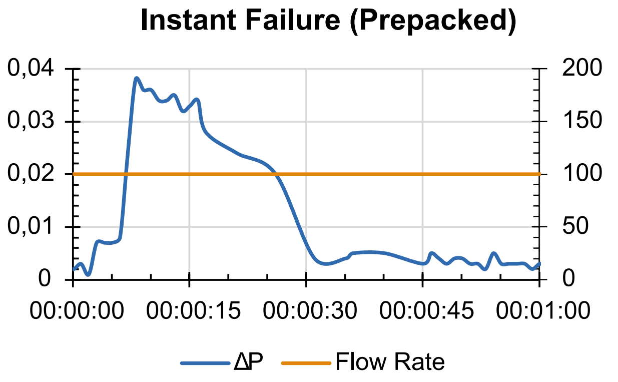

Fig. 16 SRT-Measurements showing the instant failure of a sand screen

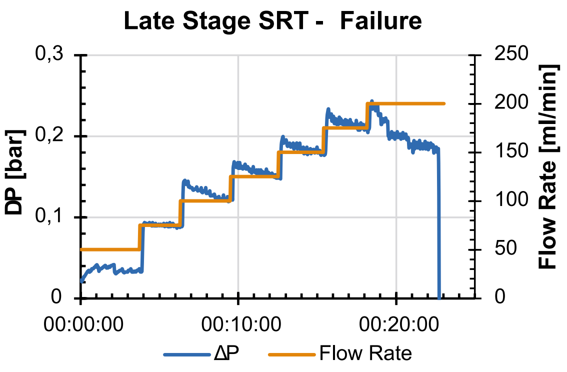

Fig. 17 SRT-Measurements showing a late stage screen failure

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