IPTC-21158-MS

Development of Plasma Sprayed Coatings to Improve the Erosion Resistance of Wire Wrapped Screens

Lukas Ochmann and Moh'd M. Amro, TU Bergakademie Freiberg; Bernd Gronde and Gundula Fischer, Fraunhofer IKTS Hermsdorf; Silke Weber, con-slot SCREENS GmbH; Dirk Martin, MUW SCREENTEC GmbH

Copyright 2021, International Petroleum Technology Conference

This paper was prepared for presentation at the International Petroleum Technology Conference held virtually on 23 March - 1 April 2021. The official proceedings were published online on 16 March 2021.

This paper was selected for presentation by an IPTC Programme Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the International Petroleum Technology Conference and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the International Petroleum Technology Conference, its officers, or members. Papers presented at IPTC are subject to publication review by Sponsor Society Committees of IPTC. Electronic reproduction, distribution, or storage of any part of this paper for commercial purposes without the written consent of the International Petroleum Technology Conference is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of where and by whom the paper was presented. Write Librarian, IPTC, P.O. Box 833836, Richardson, TX 75083-3836, U.S.A., fax +1-972-952-9435.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Abstract

The installation of sand screens in wells can fail in one of two ways: by causing an unacceptable high pressure drop in the near wellbore area or by losing the ability to retain particles. Four mechanisms can lead to a failure: plugging, corrosion, erosion and mechanical deformation. To increase the lifetime under erosive conditions, a coating for wire wrapped screens was developed and tested.

Erosion occurs, when formation particles hit the screen surface with high velocities or by continuous production of fines through the screen openings. The screen openings must keep a specified size in order to control the formation sand or gravel pack. If the opening size increases due to erosion, more particles are produced and erosion increases. A newly developed coating is put on the outside (i.e. facing the formation) of standard wire wrapped screens to make the slots resistant against erosion. The coating consists of ceramic or hard metal and is applied by plasma spraying. An extensive development and verification program was conducted to guarantee defined slot widths, corrosion resistance and mechanical strength of coating and screen.

A test facility was built to investigate the erosion resistance of sand screens. It consists of a flow loop to circulate a slurry of water and particles through 2″ coupons. Samples of standard wire wrapped, metal mesh and coated screens were tested. The tests were conducted with flow velocities of up to 18.5 m/s and particles of up to 100 micrometer for up to 60 h. The screens where compared under consideration of optical criteria, mass loss and functionality. The coated screens showed no sign of wear on the outside and kept their initial slot size. The slots of uncoated wire wrapped screens more than doubled in some places, when eroded under the same conditions. To test the functionality of the samples, sand retention tests were conducted before and after erosion. Since there were no changes in slot width, the coated screens show the same retention capabilities before and after erosion, while metal mesh screens that were eroded under the same conditions lost their ability to retain sand.

The newly developed coating improves the resistance against erosion, is able to withstand corrosive well environments and has mechanical properties suitable to be safely installed in any well. Therefore the coating has the ability to improve the lifetime of screens under erosive conditions.

Introduction

The mobilization, transportation and deposition of solid formation particles are a major problem in many oil, gas and geothermal wells. These processes are summarized under the term sand production. It can be distinguished between the production of large particles (load bearing) and small particles (fines). Apart from the particle size, sand production can be differentiated in the place of deposition (i.e. near wellbore area, wellbore, surface facilities) where it generates various problems. Over the last century, a number of operational procedures and completion elements were developed to counter sand production. One of them are mechanical sand screens. These are installed in front of the productive zone in a casing or open hole and can be used alone (Standalone Screen) or as part of a gravel pack. A sand screen has failed, if it is unable to control mobilized formation solids or by causing an unacceptably high influence on the production rate. Four distinct mechanisms can lead to a failure: erosion, corrosion, plugging and mechanical deformation. All mechanisms have different root causes during design, installation, production or workover but can also influence each other.

A mechanical failure can occur during installation or workover when tensile forces exceed the limit of the screen. During production, a screen can collapse or burst if a pressure differential between the inside and outside arises due to plugging. Plugging of screens in wells is defined as the development of a low permeable zone in the annulus between screen and formation. Plugging can have its origin in many different operational and design errors such as installation in unconditioned mud, resorting of particles from different layers, small screen openings or scaling. Corrosion depends on the combination of screen material, reservoir- or work-over-fluids and pressure/temperature conditions. It can lead to a mass loss and failure of sand retention or mechanical deformation. High flow rates in combination with formation solids can lead to an erosional failure. The erosion increases the opening size of the screen until it loses its ability to retain the sand. At this point the erosion dramatically increases due to excessive sand production[1]. Erosion is especially dangerous in gas wells but oil and geothermal wells can also experience erosional failure if the production rate is too high and concentrated on small percentages of the screen[2].

To improve the erosion resistance of wire wrapped screens, a coating was developed. It is applied to the outside of the screen by thermal (plasma) spraying and consists of hard metal or ceramic. The material is harder than stainless steel and also harder than formation solids and therefore less prone to erosion. Ceramic materials have already been used in the past for sand control screens. The development and investigation of those screens is extensively documented in many publications[3][4][5][6][7], but the screens continue to fail up to this date due to a complex design[8]. The newly developed screen uses the simplicity and proven concept of wire wrapped screens and combines it with the superior properties of erosion resistant materials such as ceramic and hard metal compounds. The development of the coating was conducted with all four failure mechanisms in mind. An extensive laboratory research program was conducted in order to prove the viability of the concept in terms of erosion resistance and sand retention capability. The applicability of coated screens in corrosive environments and deviated wells was also investigated.

Thermal Spraying and Composition of Coatings

The screens are coated using the method of thermal spraying. This process uses a hot plasma jet to melt powdery materials and apply them to a solid surface. The molten particles solidify on the surface and form a hard coating with little porosity. The adhesion of the coating is purely mechanical. There is no chemical reaction between the base material and the coating.

Several different steps are necessary to coat a wire wrapped screen. First, the screen is sandblasted in a distinct way to provide a defined surface roughness. This step is required to improve the mechanical bonding between the two composites. After that, a thin bonding layer is applied by thermal spraying. This intermediate layer further improves the adhesion of the functional layer. This erosion-resistant main layer, which consist of hard metal or ceramic is applied next; also via thermal spraying. The coating is finished by

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

filling up the pores of the sprayed layers with a liquid sealer. The sealer hardens under thermal treatment. This step drastically improves the corrosion resistance of the composite. Fig. 1 schematically shows the coating steps, layers, and final product.

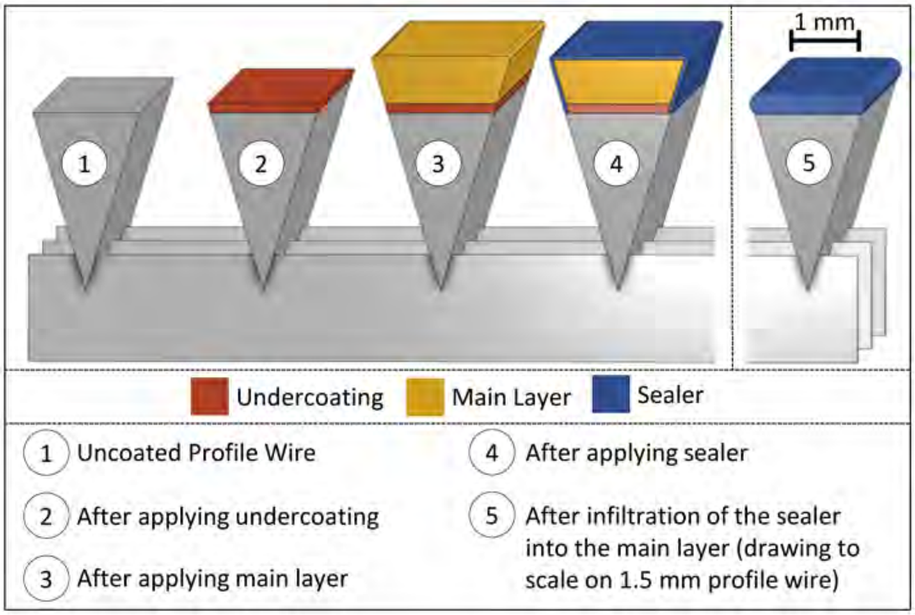


Figure 1—Schematic visualization of the coating steps, coating layers and final product

As can be seen in Fig. 2 the coating changes the geometry of the slots. It slightly reduces the slot size and creates a less sharp slot opening. The surface of the coating has a higher roughness than the steel. By adjusting the process parameters of the thermal spraying and choosing the correct initial slot width, defined and constant slot widths can be produced for the final product.

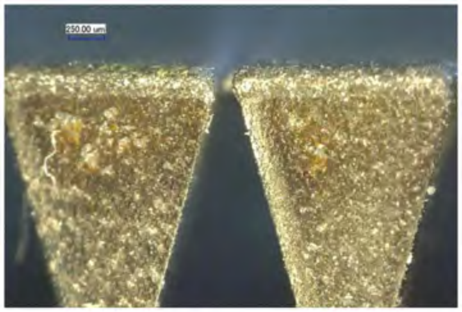


Figure 2—Side View of a Hard Metal Coated Sample

Corrosion investigation

Corrosion of well completion components depends on the chosen material (i.e. stainless steel grade), wellbore and reservoir fluids, and the pressure and temperature conditions in the well. The corrosion investigation focused on the bonding between coating and steel. The corrosion resistance of the single materials was not investigated.

All samples and the future prototypes are based on 1.4404 (316L) stainless steel. Combinations of four bonding layers, six functional layers and five sealers were investigated.

In total, 237 different samples were corroded under different conditions. Conventional well conditions were investigated using a brine with chloride, sodium, calcium, magnesium, and sulfate ions and a pressurized (10-20 bar) CO_2-atmosphere. The samples were submerged halfway into the brine so that the

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

effect of the three-phase interface (brine, gas, and sample) could be investigated over a period of multiple weeks (minimum 3 weeks, maximum 18 weeks) at 60 °C. Further experiments were conducted with nitrogen and hydrogen atmospheres for three weeks. The samples had two different geometries as can be seen in Fig. 3 and Fig. 4. The first tests were conducted with samples made from wire wrapped screens. A second batch of tests was performed with coupons for tensile bond tests. An example for a failed sample is shown in Fig. 5 where a functional layer without bonding layer separated from the steel wires after three weeks of corrosion.

Figure 3—Coated Sample after 18 weeks of Corrosion

Figure 4—Coated Coupons before Corrosion

Figure 5—Example for a separation of screen and coating without the use of a bonding layer

In addition to normal conditions, acid stimulation was also a concern. The impact of short time interaction with acid was investigated using 10% hydrochloric acid. Coated samples were again halfway submerged into tempered (60 °C) acid for a period of 46 h at atmospheric conditions. These experiments were especially helpful to detect good sealers. In conclusion, multiple coating combinations were identified that withstood all tested corrosion environments. The experiments clearly showed the positive effect of bonding layers and sealers on the bonding of thermally sprayed coatings under wellbore conditions.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Deformation

Stability investigations on sand screens should be conducted according to ISO 17824. This standard summarizes requirements and guidelines for the design, design validation, construction, storage, transport and quality of sand screens. The described tests in the appendix of the standard are suitable to investigate entire sand screens but not for the present case of failure due to deformation of coated wire wrapped screens.

The coating does not contribute to burst, collapse or axial stability. All these ratings are based on the uncoated wire wrapped screen geometry and material. Similar to the corrosion experiments, the goal of the mechanical tests was to investigate the behavior of the composite under external influences. A failure of coated screens could theoretically occur if the screen is deformed (elastic or plastic) and tensions between the compound-materials lead to a separation of the compound. This could be the case in horizontal wells with high doglegs. Bonding strength and deformation where therefor investigated using small scale samples.

The bonding between thermally sprayed layers and base materials was investigated by tensile bond tests based on ISO 14916. The results of these experiments gave information about the influence of the surface treatment (sand blasting) and bonding layer on the bond strength. It was also found out, that the particle size of the powder had an impact. Fig. 6 shows the measured bonding for a compound of a bonding layer and a zirconium oxide (ZrO_2) functional layer. The results show that fine powders lead to a better bonding than coarse raw materials.

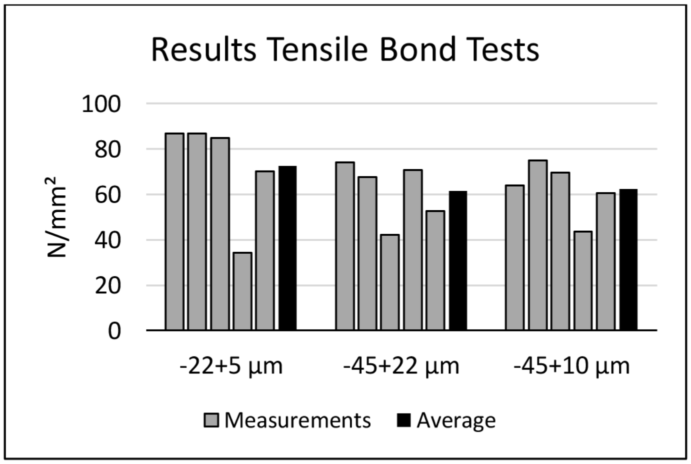


Figure 6—Measured tensile bond strength for different raw material particles sizes

Deformation of the coated wires of the screens can be the result of bending or torsional forces. Therefore, additional experiments were performed by bending and twisting coated steel rods. The rods have length of 105 mm and a square base with a width of 5 mm. They are inserted into an apparatus (Fig. 7) and loaded with an increasing force that creates bending or torsional tensions. The coated rods were able to withstand the highest applicable loads (700 N) without separation of the compound materials. Separation only occurred when rods where manually twisted to 30°. This amount of torsion is extremely unlikely to act on the coated wires in wells during installation, operation or workover.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Figure 7—Apparatus for bending experiments

Figure 8—Coated steel rods after torsional experiments

The material of the investigated samples (steel and coating) was similar to the planned prototypes. The deformations that lead to a separation of the compound parts were very large and far away from deformations that occur in wells. It can be concluded that the mechanical properties of the coated screens are not a limiting factor for the use in wells.

Liquid Erosion

To investigate the erosion resistance of sand screens a test facility was built. The facility enables water to continuously flow through screen samples in a flow loop. The loop consists of a tank that holds up to 10 l of slurry. A peristaltic pump pumps the slurry into a cell that holds the samples. A valve behind the cell allows taking slurry samples and draining the loop. Different sensors measure the flow rate and various pressures inside the cell.

The facility was updated and improved several times during the project. It was originally designed to erode the screens with an open area of 30% with a velocity of 1.5 m/s (in the slots). This velocity was chosen based on previously published findings that indicated a safe velocity for liquid flow through sand screens of 0,3 m/s (1 ft/s)[1][9]. Although being five times higher, it was quickly discovered, that this velocity was not enough to erode the samples by a measureable amount within reasonable time. Therefore, the slot velocity was increased by using a metal orifice. This increased the velocity of the investigated samples up to 12 m/s. Later within the project the pump was changed to further increase the flow rate and erode screens with up to 18 m/s slot velocity (60 ft/s). In addition to the pump change, a cooling spiral was added to the tank. Without cooling, the slurry-temperature would rise above 60 °C and could damage the pump. The final stage of the development of the flow loop is shown in Fig. 9.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

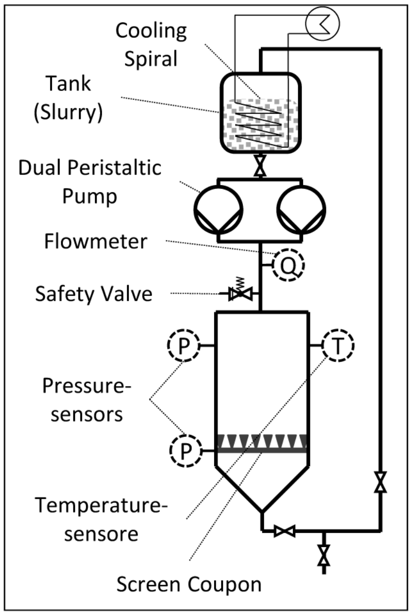


Figure 9—Schematic of the Erosion Flow-Loop

The samples (see. Fig. 10) that can be eroded in the facility, are flat 50 mm coupons and were cut from wire wrapped screens. Coated samples were manufactured by coating coupons not by cutting samples from coated wire wrapped screens. The process was comparable to the coating of real screens. Mesh screens were rebuild by combining different layers of perforated plate (RV5-8, representing the inner and outer shroud), 1 mm plain mesh (representing a drainage layer above and below the middle layer) and plain dutch mesh in the middle (representing the sand control layer with the corresponding filter cut point). Cutting samples from metal mesh screens was not possible. The mesh samples used for this investigation are comparable to what has been used in other publications[1][2][10].

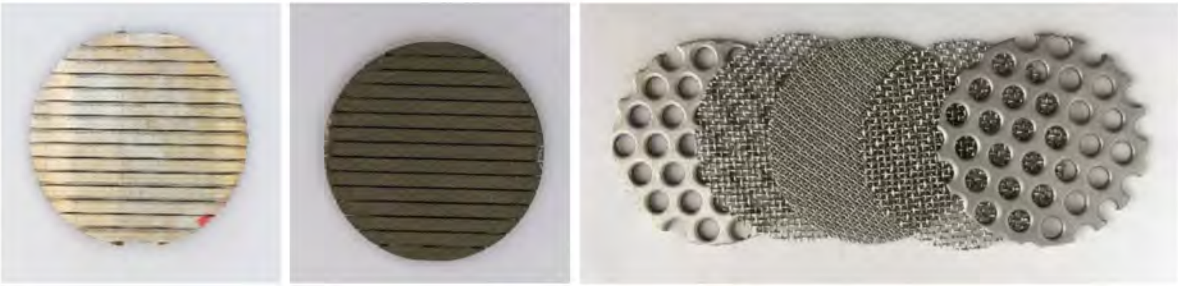


Figure 10—Screen Samples (left: uncoated, middle: coated, right: mesh screen layers)

Experiments were conducted with various samples under different flow rates. Other conditions were kept constant and are summarized in Table 1. The flow conditions and goals of the different test series can be seen in Table 2. The table also summarizes the investigated samples. The wire wrapped screens were made from 1.5 mm (V15) or 3.0 mm (V30) wires. The particle concentration was 0.5 % (5 g/l). The particles were sieved to a size that avoided bridging on the slots. All samples had a nominal opening of 200 pm. The particle size distribution can be seen in Fig. 11.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Table 1—Parameters of the Liquid Erosion Tests

Parameter	Value
Diameter of Screen Samples	50 mm (~2 inch)
Diameter open to flow	38 mm (1.5 inch)
Fluid	Water
Particle Concentration	5 g/l (0.5 %)
Particle Type	Quarz (SiO_2)
Particle Size D_{50}	23 pm

Table 2—Flow Conditions of Erosion test series

	Series 1	Series 2	Series 3
Goal	Bringing into service, Influence of Particle concentration, Influence of Flow Rate/Flow Velocity	Comparative Investigation of different samples under equal conditions	Comparative Investigation of different samples under equal conditions
Opening Velocity	variable	~12 m/s	variable
Flow rate	variable	variable	80 1/min
Challenged Diameter	variable	19 mm	38 mm
Tested Samples	V15 WWS SW = 0.2 mm	• V15 WWS • Coated V15 WWS • Mesh Nominal Opening 0.2 mm	• V30 WWS • Coated V30 WWS • Mesh Nominal Opening 0.2 mm

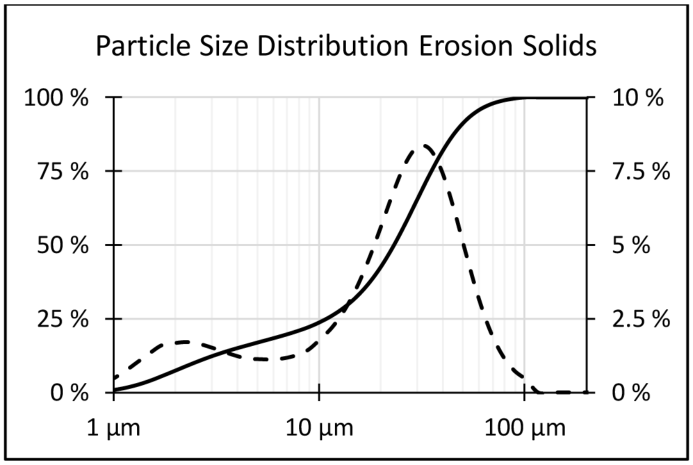


Figure 11—Particle Size Distribution of the solids used during the liquid erosion tests

Observations

Mass loss beyond the uncertainty of measurement was not observed for wire wrapped screens when eroded with fines up to a flow velocity of 2.5 m/s (see Fig. 12). Considerably higher velocities were necessary to remove measurable amounts of mass from the samples.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

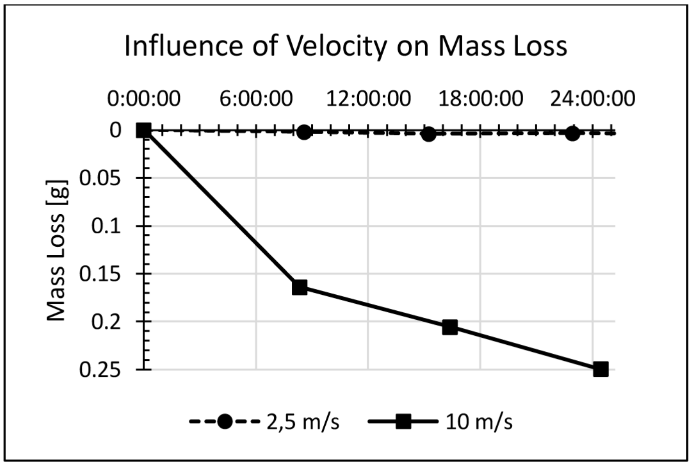


Figure 12—Mass loss of two similar samples at different velocities

Two mass loss curves are shown in Fig. 13 and Fig. 14. The data indicates no significant difference in erosion between coated and uncoated screens. Mesh screens show the highest mass loss of all screens. Especially the relative mass loss of the sand control layer is noteworthy.

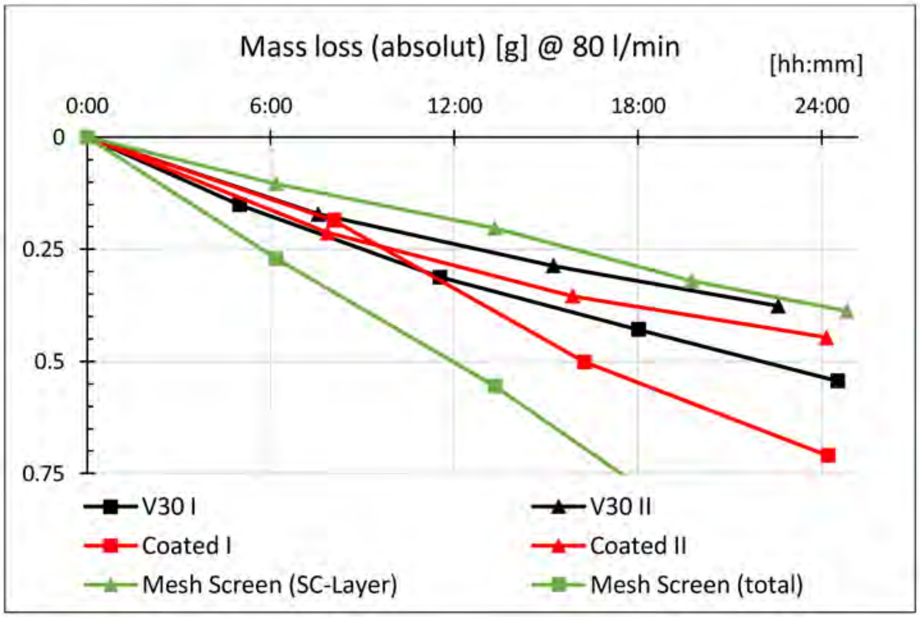


Figure 13—Absolute mass loss of several samples eroded under the same conditions

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/D012S041R002/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

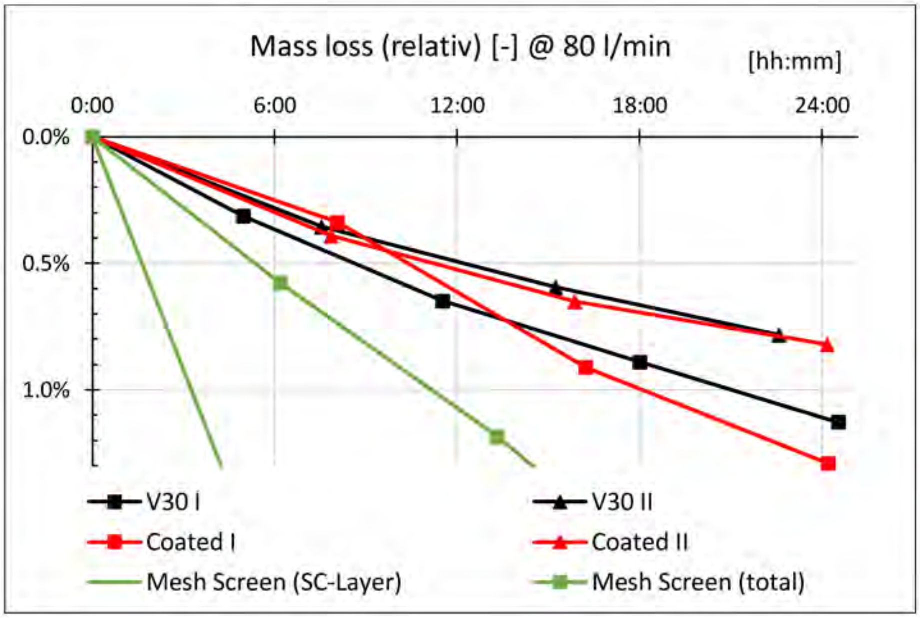


Figure 14—Relative mass loss of several samples eroded under the same conditions

An optical investigation of the samples revealed, that wire wrapped screens eroded at three different places during the experiments: outside at the slot opening, on the sides of the profile wire, and on top of the support rods (see Fig. 15). Coated screens showed only little signs of erosion on the outside, whereas uncoated screens that were eroded under the same conditions showed significant material removal. The sand control layer of mesh screens was severely damaged in some places where the wires were completely eroded (Fig. 16).

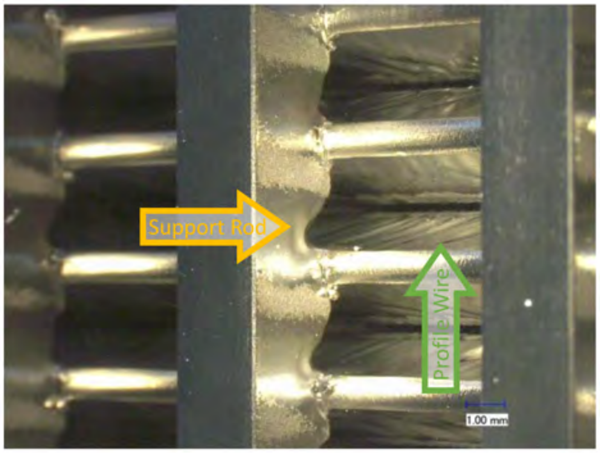


Figure 15—Example for Erosion on Support Rods and Profile Wires

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

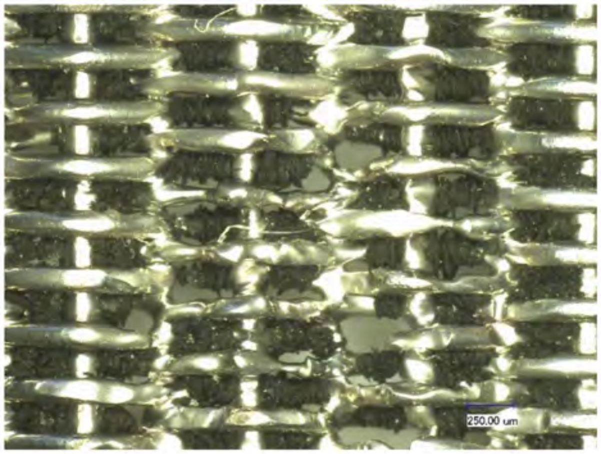
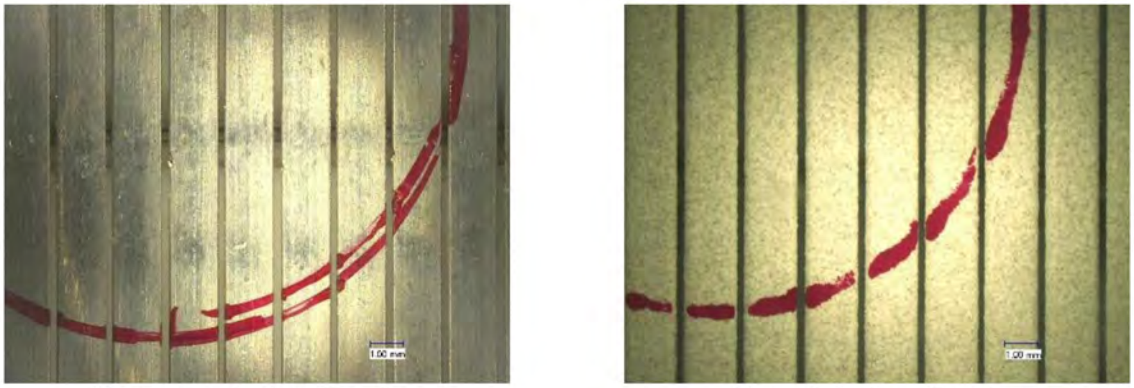
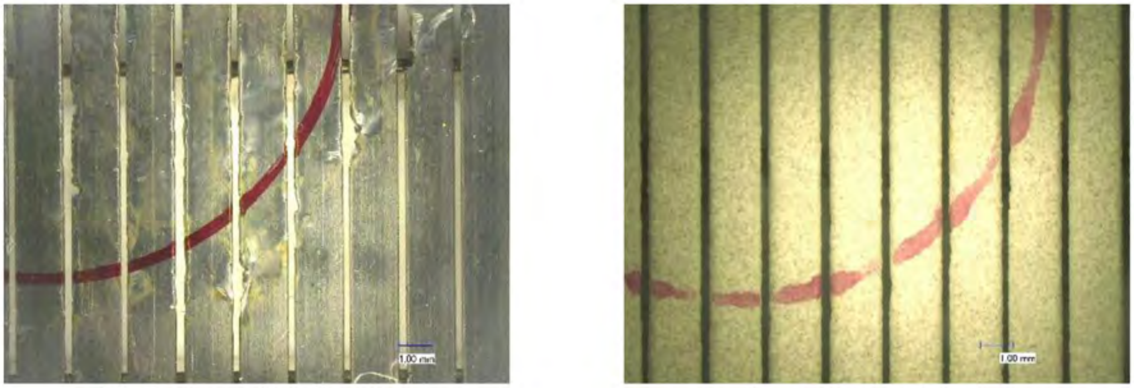


Figure 16—Example for Erosion on a mesh screen sand control layer



Uncoated, before Erosion Coated, before Erosion



Uncoated, after Erosion Coated, after Erosion

Figure 17—Comparison of coated and uncoated screen samples (series 2) before and after erosion

Cavitation during liquid erosion

One concern after reviewing the results of the liquid erosion was that cavitation occurred within the samples. Cavitation could have increased the mass loss of the sample independent of the particles or increased the effect of the particle collisions with the samples. The experiments were therefor repeated without particles. Samples that are eroded without particles lose at least one order of magnitude less mass than samples that are eroded with particles. The measured mass loss of those samples was very low and likely effected by the accuracy of the measurement.

To further investigate cavitation within the system, acoustic measurements were conducted. Acoustic measurement is a well-established method to detect cavitation. The detected cavitation noise is a result of

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

the collapse of the formed bubbles. Characteristic noises occur at frequencies between 1 kHz and 100 kHz[11] [12][13]. A piezo sensor was mounted to the upper part of the cell. Noises between 10 Hz and 50 kHz were measured. The signal was transformed to the frequency band using Fast Fourier Transformation. The result can be seen in Fig. 18.

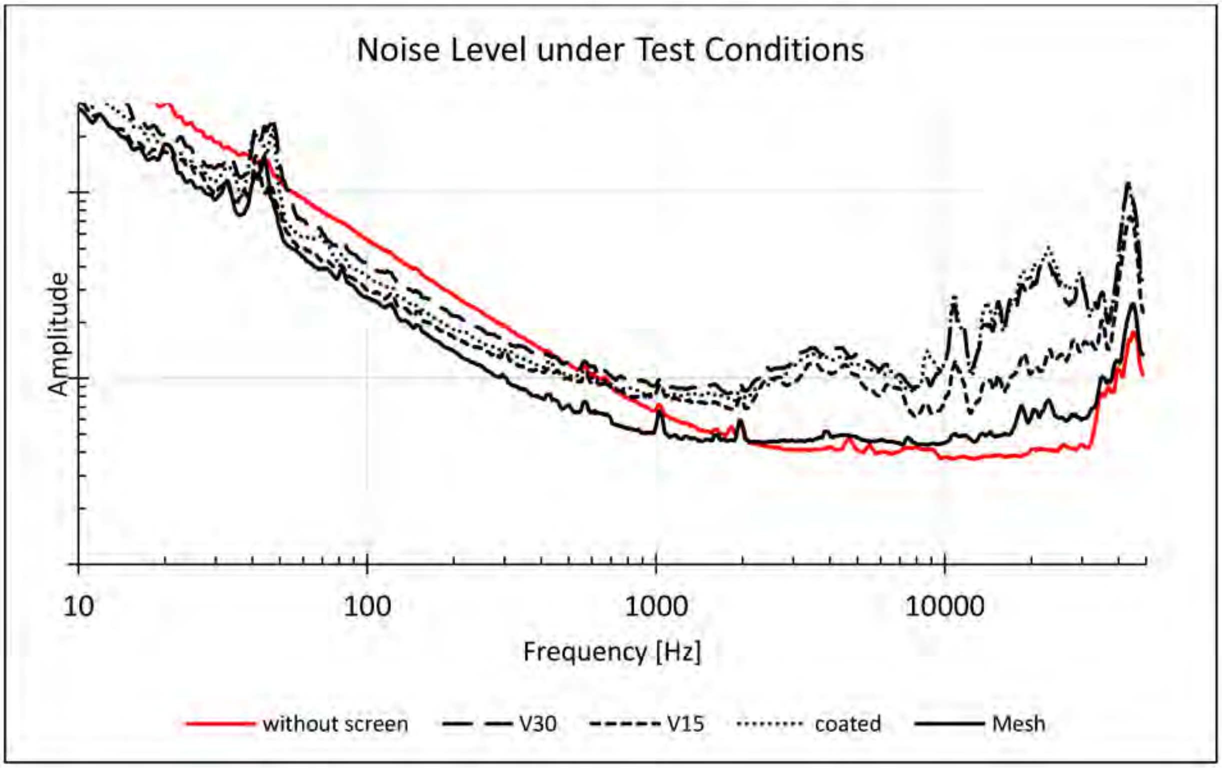


Figure 18—Measured noise levels under test conditions to investigate cavitation

The red curve shows the noise level in the cell without a mounted sample at a flow rate of approximately 80 l/min. Four different samples (V30, V15, Coated V30 and Mesh) were then measured at the exact same flow rate. It can be seen, that the flow through wire wrapped screens generates noises at frequencies above 2 kHz that are very different from the mesh sample and the base case without a screen. The noises are interpreted to be the result of cavitation. The occurrence of cavitation is a major shortcoming in the design of the test facility. Cavitation in sand screens does not occur in wells, due to the increased pressure. However, the main questions that arise from the finding are:

a. Why do metal mesh screens show the highest mass loss but no cavitation?
b. Why do coated and uncoated screens loose similar amounts of mass but erode at different places?

Flow Regimes during Erosion

Erosion occurs if particles hit a solid surface with sufficient impact energy. The number of interactions is dependent on different factors of which some are similar for all samples, such as particle concentration and fluid viscosity. A significant difference between the samples is the regime of the fluid flow that passes through them; or in simpler terms: how turbulent it is. The more turbulent a flow is, the more likely particles interact with the samples. The flow regime can be expressed by the Reynolds number (Re). It is a dimensionless quantity that combines inertial forces and viscous forces and defined as:

$$Re = \frac{\rho v d}{\eta} = \frac{v d}{\nu} \tag{1}$$

For flat wire wrapped screens, Re is constant throughout the slot and calculated as:

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

$$Re = \frac{Q \cdot \rho \cdot (B + SW_a)}{\frac{\pi}{4} D^2 \cdot \eta} \qquad (2)$$

The formula is applicable for both coated and uncoated samples, but not for mesh screens. Re was calculated for each layer of the screen. Formula (1) was used for the perforated plates. Re within the mesh layers was calculated according to the work of Armour and Cannon[14]. These numbers cannot be directly compared to other Reynolds-Numbers. Instead they have to be reviewed by themselves. In meshes, Re below 5 is considered to indicate laminar flow, above 50 the flow is turbulent[15]. The flow in the transition zone in between depends on the exact conditions (i.e. mesh geometry, fluid properties, etc.).

The calculated Reynolds numbers are 3700 for uncoated V30 samples and 3873 for coated V30 Samples (SW = 0.2 mm, Q = 80 l/min). The resulting numbers for the plain dutch mesh (sand control layer) are 6.60 and 667 for the plain square mesh (drainage layer). This means, that the flow through a metal mesh screen under the chosen erosion conditions is mostly turbulent except for the sand control layer, which is in the transition zone. The flow through the wire wrapped screen samples is in the transition zone. The flow is assumed to be laminar at the smallest slot opening. Within the slot the flow then separates from the contour of the profile wire and becomes turbulent. Due to the higher Re and different geometry (less sharply defined edges, higher surface roughness, unsteady slot contour), the flow in the slots of coated screens is assumed to be more turbulent.

Discussion of liquid erosion

The necessary flow velocity to erode screen samples was much higher than expected from the literature. The chosen erosion conditions for comparative experiments are at least one order of magnitude higher than the expected conditions in wells. Erosion is dependent on many different factors such as flow velocity (at different positions such as slot, before screen, etc.), particle size, mineralogy, etc. Therefore, we conclude, that although mass loss was hardly measureable at flow velocities below 2.5 m/s (~8 ft/s), a safe flow velocity cannot be defined based on our measurements. However, it is possible to make statements about the erosional behavior and point out advantages and disadvantages of the different screens. Wire wrapped screens showed (on average) the least amount of mass loss. This mass loss mostly occurred at the slot opening. Metal mesh screens showed the highest mass loss throughout all test series, both absolute and relative. The mass loss was especially significant at the middle layer responsible for the retention of formation particles. We interpret that this mass loss is due to increased turbulence in the mesh screens compared to wire wrapped screens. The results of the cavitation measurements indicate a higher flow capacity (lower pressure drop) of mesh screens in the tested configuration and an advantage in solids free wells. The coating that was applied to the wire wrapped screens makes the slot openings very resistant against erosion. The location of the mass loss changes to the inside of the screens, where the damage has hardly any immediate influence on the sand control capability. The higher mass loss of the coated screens compared to the standard V30 samples is most likely a result of increased turbulence within the slot. The increase is caused by the discontinuous slot shape and higher surface roughness. We conclude that the coating is a significant improvement for wire wrapped screens in terms of erosion resistance despite a higher internal erosion.

Sand Control

The sand retention properties of the screens were investigated using prepacked tests. The facility for these tests was built for the development of this product. Therefore, it was constantly improved and updated throughout the project. A schematic of the facility is shown in Fig. 19.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

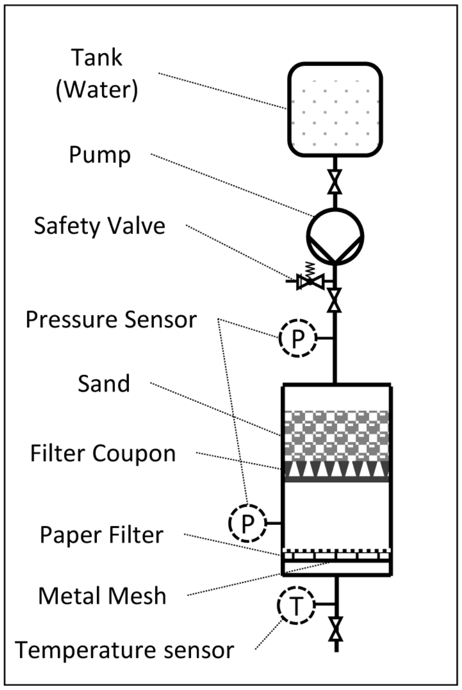


Figure 19—Schematic of the Sand Retention Test Facility

Inspiration for the construction of the facility was taken from various sources such as Markestad et. Al.[16], Ballard and Beare[17][18] and Fischer and Hamby[19]. The test rig is set up to take two key measurements: The amount of produced sand and the pressure drop across screen and retained sand. The collected data can be compared between different screen samples, screen types, opening sizes, particle size distributions etc.

The facility consists of a cell that holds the same 50 mm flat screen samples as the erosion flow loop. The water is pumped with an HPLC-Pump from a tank into the cell and through the sand pack and a sample. Tests can be run at flow rates between 1 ml/min and 500 ml/min. Pressure sensors are placed above and below the sand pack. The temperature of the fluid is measured at the outlet.

Two different types of test cells were developed and used during the project. Both are designed for the same samples and have an open flow diameter of 38 mm with a cylindrical sand bed above the screen. The first is manufactured from stainless steel and can withstand pressures of up to 50 bar and temperatures of up to 80 °C. This cell was used to evaluate the sand retention performance before and after erosion. It measures the pressure drop across the screen sample and sand pack as well as the pressure directly above the screen. The produced sand is collected using folded paper filters in a funnel below the outlet. The produced sand can be determined by measuring the mass difference of the filter paper before and after the test.

The second cell features two significant updates. It is partly transparent and allows to collect produced sand directly on a flat 50 mm paper filter a few centimeters below the sand screen sample. There are no restrictions below the sand screen so that all produced sand will fall onto the paper filter. The paper filter can be burned without creating ash. This allows to quantify the exact amount of produced sand. The cell is limited to pressures of around 3 bar and ambient temperature. This cell was used to further investigate differences between coated and uncoated screens. The current design (Fig. 20) also features a port above the cell where a slurry or sludge can be injected into the main flow to perform slurry tests. Slurry tests are not part of this publication.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

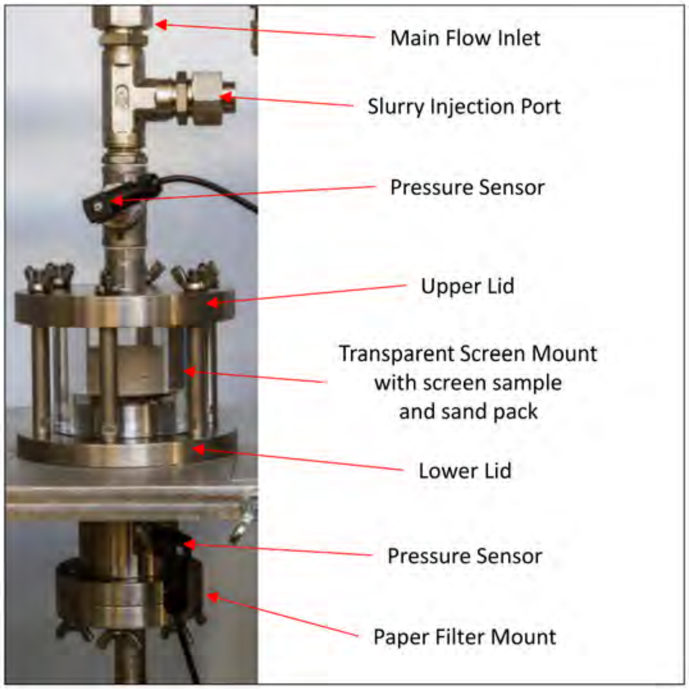


Figure 20—Transparent SRT-Test Cell

All experiments were conducted using the same particle size distribution. Every sample had a nominal opening size of 200 pm. The sand was sieved to have about 10 % of the particles larger than 200 gm. The measured distribution can be seen in Fig. 21. The difference between sieve and laser diffraction analysis can be explained by the differences in the measurement principles and grain shape.

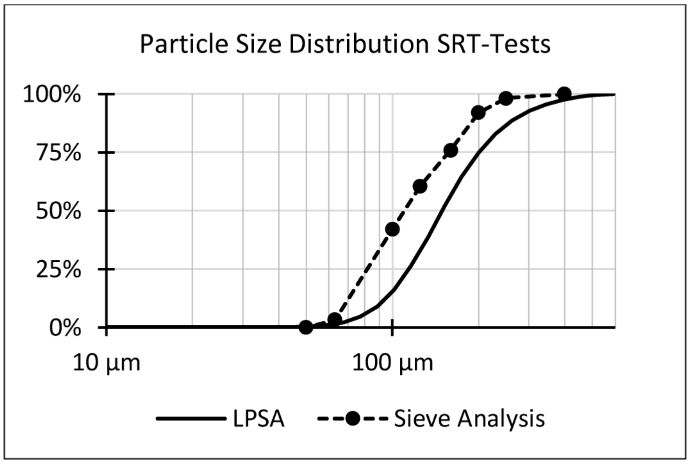


Figure 21—Particle Size Distribution of the sand mixture used for SRT-Tests (Sieve and Laser Diffraction Analysis)

Sand Retention before and after Erosion

To find out, if the liquid erosion lead to loss of sand retention capability, comparative sand retention tests were conducted before and after erosion. Each screen sample was tested three times: twice before erosion and once after erosion. The tests before erosion were used as a benchmark. The samples were all eroded under the same conditions (erosion series 2 or series 3). The experiments were prepared by mounting a screen sample in the cell. Then water was poured into the cell until it is filled to the top of the screen. After this, the loose sand was placed on the screen sample. This procedure was chosen to prevent too much sand from falling though the screen prematurely. The sand was then saturated with water and the whole

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

apparatus filled with water. The test itself was started at a low flow rate and then increased stepwise before reducing back to the initial rate. The goal of this procedure was to find out if failure occurred immediately or just at higher flow rates and if the pressure drop changed during the test due to sand production. All coated screens were able to retain the sand after erosion. The same applies for uncoated screens. It turned out, that the erosion conditions were not challenging enough for wire wrapped screens. Surprisingly, two of three investigated mesh screen samples failed. An example can be seen in Fig. 22. The chart shows the stepwise increase of flowrate from 50 ml/min to 200 ml/min. Each step shows an increased pressure drop that stabilizes after about three minutes. At the highest flow rate, the pressure did not stabilize and it decreased significantly, simultaneously a large amount of sand production was observed.

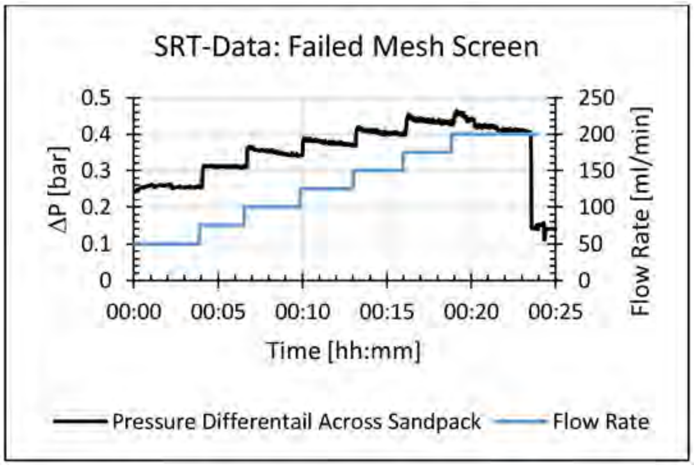


Figure 22—SRT-Measurements showing the failure of a sand screen

Comparative Sand Retention Tests

One major shortcoming of the early Facility was the error-prone measurement of the sand production. To improve this, the second cell was constructed and more experiments conducted to compare the performance of coated and uncoated screens. The produced sand is determined by a differential measurement of the weight of a ceramic cup before and after burning the paper filter with the sand. The paper is rated for quantitative analysis and has an ash content of only 0,007% after burning.

The tests were prepared in the same manner as before. The flow rates were 100 ml/min, 200 ml/min and 300 ml/min. After reaching the highest rate, the flow rate was decreased in the same steps. Each step lasted three minutes. Three different samples were investigated: A coated V30-sample, an uncoated V30 sample and a mesh screen. All samples had a nominal screen opening of 200 pm and each sample was tested five times. The amount of produced sand was averaged (see. Fig. 23). To eliminate the influence of slot variations, the produced sand was then divided by the open area of the samples to calculate a specific mass (Fig. 24). This value represents the amount of sand that is produced per open square meter of the screen. The slot width was measured with a microscope. The open area of the mesh screen is a combination of the open areas of the single layers and was estimated to be approximately similar to the V30 wire wrapped screen. The pressure data was used to calculate the permeability. The data for the coated sample can be seen in Fig. 25 and Fig. 26.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

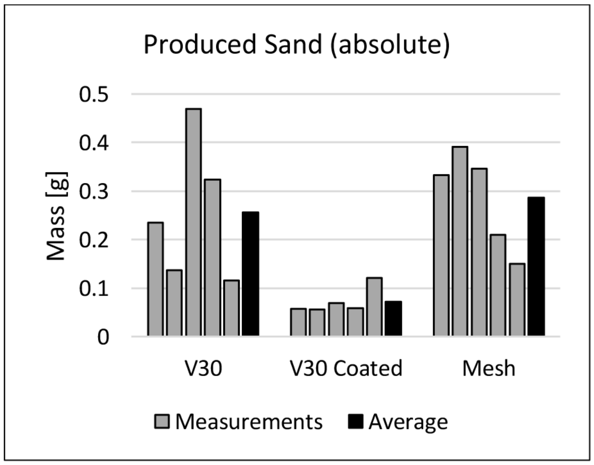


Figure 23—Produced mass of sand during SRT-Tests

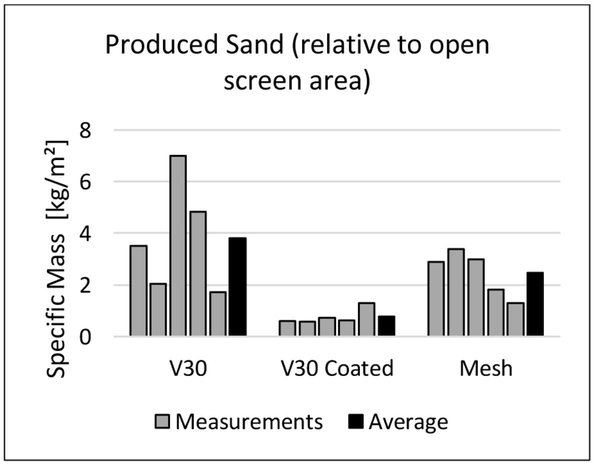


Figure 24—Produced masses of sand relative to open screen area

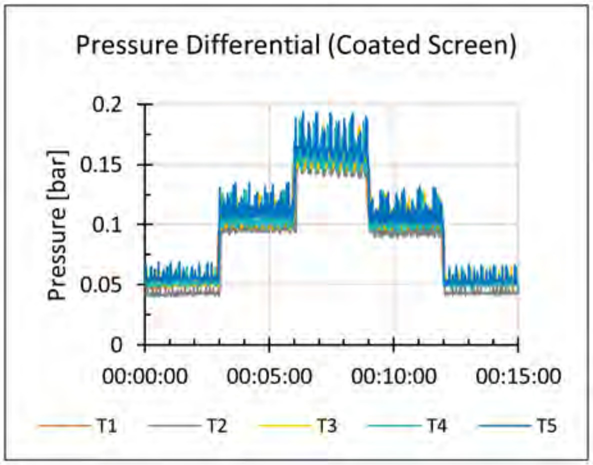


Figure 25—pressure differential for five tests of the coated screen sample

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

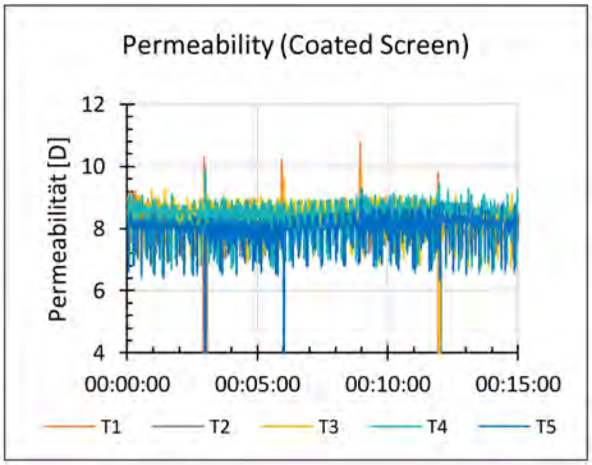


Figure 26—Calculated permeability for the coated screen sample

All screens were able to retain the particles after some initial sand production. However, the amount of sand that was produced was different for each sample and even each test. The coated screens produced less sand both absolute and relative compared to the other screens. This is likely due to a slightly smaller slot width. The mesh screen produced the most amount of sand in absolute terms but slightly less relative to the open screen area. It should be remembered that the open area of the mesh screen was only estimated. We conclude that there is no significant difference in sand retention capability between the mesh and the V30 wire wrapped screen sample. Pressure drop and permeability were similar for all three samples.

Conclusions

- Wire Wrapped Screens can be coated with erosion resistant materials by thermal spraying.
- The coating consists of three layers of different materials that each fulfill a distinct purpose.
- Samples of coated and uncoated screens were tested on all four failure mechanisms: erosion, corrosion, deformation and plugging.
- The compound is resistant against corrosion and the coating sticks to the steel wire under corrosive conditions if the right materials are combined in the different layers.
- The mechanical properties of the coated screens are determined by the base stainless steel screen. Separation of coating and steel due to tensions from mechanical deformation during installation, operation or workover is unlikely. The mechanical strength and elastic deformation are not limiting factors for the usage of coated screens in wells.
- Traditional (uncoated) wire wrapped screens erode on the outside and on the inside.
- Coated sand screens erode from the inside out when a slurry flows through them due to increased internal turbulence compared to uncoated screens.
- Since the slot width is kept constant by the erosion resistant coating, the lifetime of the newly developed screens will be longer under erosive conditions.
- Screens that result in higher internal turbulences are more susceptible to mass loss.
- Mesh screens (Premium Screens) are more prone to erosional failure by continuous fines production than wire wrapped screens.

The coating has no influence on the sand retention capabilities of the screen. Measured differences in advantage of the coated screens are most likely due to manufacturing tolerances of the tested prototype samples.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Acknowledgement

Some parts of this project were funded by the German Federal Ministry for Economic Affairs and Energy.

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

ZIM
Zentrales
Innovationsprogramm
Mittelstand

List of Symbols

B - Width of Profile Wire m
d - characteristic Length m
D - Diameter of Screen Sample open to Flow m
η - Dyn.-Viscosity Pas
V - Kin.-Viscosity m^2/s
Q - Flow Rate m^3/s
ρ - Density Kg/m^3
Re - Reynolds Number -
SW_a - Slot Width on the outside m

Literature

1. J. Cameron und C. Jones, "Development, Verification, and Application of a Screen Erosion Model", *SPE European Formation Damage Conference, Scheveningen*, 2007, SPE-107437.
2. G. Gillespie und C. Jones, "Sand Control Screen Erosion — When Are You at Risk?", *SPE European Formation Damage Conference, Scheveningen*, 2009, SPE-122269.
3. S. Miissig, S. Wagner, A. Kayser, und S. Wildhack, "The development of ceramic screens to prevent sand influx and erosion in stimulated production wells", *Oil Gas European Magazine*, Bd. 36, Nr. 3, S. 126–130, 2010.
4. S. Wildhack, S. Miissig, F. Strahammer, und M. Leitner, "Sand control with ceramic screens in unconsolidated reservoirs demonstrated in the mature Gaiselberg oilfield", *Oil Gas European Magazine*, Bd. 38, Nr. 2, S. 74–78, 2012.
5. B. A. Andiappan, H. Hofstätter, S. Müssig, und P. Barth, "Investigation of Plugging and Scaling Processes on Ceramic Sand Screens, the New Approach for Sustainable Oil and Gas Production", *OIL GAS European Magazine*, Nr. 3, S. 130–136, 2014.
6. P. Cadogan, S. Hall, R. Jackson, F. Meschke, T. Read, B. Gundemoni, und P. Barth, "Ceramic sand screens: Qualification strategy for a high rate gas application", Society of Petroleum Engineers - SPE Asia Pacific Oil and Gas Conference and Exhibition 2018, APOGCE 2018, 2018, DOT: 10.2118/191931-ms.
7. N. Manning, P. Cadogan, P. Barth, B. Hoskin, T. Read, D. Manning, R. Jackson, und B. Gundemoni, "Performance of Ceramic Sand Screen for High Rate Gas Application - Gas Sand

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021

Screen Erosion Testing Background: Erosion System", SPE Asia Pacific Oil & Gas Conference and Exhibition, 2018, SPE-191942.

8. B. R. Gundemoni, S. R. Jackson, J. Zimmermann-Ptacek, P. Barth, K. N. Idris, W. J. Yeap, und T. L. Catherine, „Ceramic Sand Screen Design Enhancement Lessons Learnt from Initial Field Installations of through Tubing Applications in Offshore East Malaysia to Improve Well Performance", Offshore Technology Conference Asia, Nr. October 2019, 2020, DOT: 10.4043/30039-ms.
9. G. K. Wong, P. S. Fair, K. F. Bland, und R. S. Sherwood, "Balancing Act: Gulf of Mexico Sand Control Completions Peak Rate Versus Risk of Sand Control Failure", Proceedings - SPE Annual Technical Conference and Exhibition, S. 3921–3931, 2003, DOT: 10.2118/84497-ms.
10. A. Procyk, X. Gou, S. K. Marti, R. C. Burton, M. Knefel, D. Dreschers, A. Wiegmann, L. Cheng, und E. Glatt, "Sand Control Screen Erosion: Prediction and Avoidance", SPE Annual Technical Conference and Exhibition, Houston, 2015, SPE-174837.
11. N. Zhang, M. G. Yang, B. Gao, und Z. Li, "Investigation on vibration characteristics in a centrifugal pump with special slope volute", *Advances in Mechanical Engineering*, Bd. 7, Nr. 2, 2015, 16878140, DOT: 10.1155/2014/936218.
12. Y. Chizelle, S. Ceccio, und C. E. Brennan, "Cavitation scaling experiments with headforms: bubble acoustics", Nineteenth Symposium on Naval Hydrodynamics. National Academy Press, Washington DC, S. 72–84, 1994.
13. C. Samuel Martin, H. Medlarz, D. C. Wiggert, und C. Brennen, "Cavitation inception in spool valves", *Journal of Fluids Engineering, Transactions of the ASME*, Bd. 103, Nr. 4, S. 564–575, 1981, DOT: 10.1115/1.3241768.
14. J. C. Armour und J. N. Cannon, "Fluid Flow Through Woven Screens", *AIChE Journal*, Bd. 14, Nr. 3, S. 415–420, 1968.
15. A. Fischer und J. Gerstmann, "Flow Resistance of Metallic Screens in Liquid, Gaseous and Cryogenic Flow", *5th European Conference for Aerospace Sciences (EUCASS)*, S. 1–12, 2013.
16. P. Markestad, O. Christie, A. Espedal, und O. Rorvik, "Selection of Screeen Slot Width to Prevent Plugging and Sand Production", *SPE Formation Damage Control Syposium, Lafayette*, 1996, SPE-31087.
17. B. Tracey und B. Steve, Media Sizing for Premium Sand Screens: Dutch Twill Weaves", Proceedings of SPE European Formation Damage Conference, 2003, SPE-82244.
18. T. J. Ballard und S. P. Beare, "Sand Retention Testing: The More You Do, the Worse It Gets", SPE International Symposium and Exhibiton on Formation Damage Control, Lafayette, 2006, SPE-98308.
19. C. Fischer und H. Hamby, "A novel approach to constant flow-rate Sand retention testing", Proceedings - SPE International Symposium on Formation Damage Control, 2018, DOT: 10.2118/189515-ms.

Downloaded from http://onepetro.org/IPTCONF/proceedings-pdf/21IPTC/1-21IPTC/2417227/iptc-21158-ms.pdf by TU Bergakademie Freiberg user on 19 March 2021