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A COMPREHENSIVE REVIEW ON SAND CONTROL IN OIL AND GAS WELLS PART II. CHEMICAL TREATMENT AND SAND MANAGEMENT

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A B S T R A C T

Sand production presents numerous technical, economic, and environmental challenges to the oil and gas industry. Sand particles may erode production equipment, resulting in increased maintenance costs and potential equipment breakdown. In addition, the influx of sand into the wellbore can lead to reduced production rates, reduced efficiency of reservoir sweep, and ultimately, reduced recovery of hydrocarbons. Also, sand production impacts project profitability because of the cost of sand control measures and potential lost production. There are two broad classes of methods used to control sand in oil reservoirs: mechanical methods are designed to physically restrict sand particles from entering the wellbore, while chemical methods involve the modification of reservoir properties to increase sand consolidation or fluid mobility. Chemical consolidation uses chemicals (resin, polymer gels, foams, nanoparticles, bacteria, etc.) to bind sand particles together to create a stable formation. For optimal sand control, combined approaches use a combination of mechanical and chemical methods. Sand management is an important part of oil and gas production, and several new technologies such as artificial intelligence and machine learning, autonomous sand monitoring systems, sand control measures, chemical sand control technologies, multilateral sand screens, advanced sand screen materials have been developed to improve sand management in the industry. Current developments and strategies in chemical consolidation techniques, sand management, control and prevention techniques are reviewed in this paper.

Keywords: sand production; chemical consolidation; resin; polymer gels; foams; machine learning; artificial intelligence; sand monitoring systems.

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Sand consolidation

Sand consolidation technologies are used to stabilize loose sand formations and prevent sand production during oil and gas production [1-3]. For this purpose, the different chemicals (mainly epoxy-based organic resins) are used, which bonds the unconsolidated formation sand grains together into a strong and permeable mass around the well bore. This prevents the dislodging of the sand grains by drag forces of the flowing fluids. Permeability to oil is reduced because the resin occupies a portion of the original pore space, and also because the resin surface is oil wet (fig.).

It is possible to estimate the reduction in the porosity of the collector due to the coating of spherical sand grains with resin layers of thickness δ (fig.). The porosity of the unconsolidated formation (ε_1) is:

$$\varepsilon_1 = \frac{V_t - N\frac{4}{3}\pi R^3}{V_t} = 1 - \frac{N\frac{4}{3}\pi R^3}{V_t} \quad (1)$$

where, R and N are the average radius and the number of a sand grains in the total volume V_t.

The porosity of the consolidated formation (ε_2) is:

$$\varepsilon_2 = \frac{V_t - N\frac{4}{3}\pi (R+\delta)^3}{V_t} = 1 - \frac{N\frac{4}{3}\pi (R+\delta)^3}{V_t} \quad (2)$$

From equation (1) for sand grains concentration $\frac{N}{V_t}$ we get:

$$\frac{N}{V_t} = \frac{1-\varepsilon_1}{\frac{4}{3}\pi R^3} \quad (3)$$

Thus, the porosity of the consolidated formation is determined as:

$$\varepsilon_2 = 1 - (1-\varepsilon_1)\left(\frac{R+\delta}{R}\right)^3 = 1 - (1-\varepsilon_1)\left(1+\frac{\delta}{R}\right)^3 \quad (4)$$

For example, for the case when ε_1=0.2, R=10 μm and δ=100 nm, we obtain a reduction in the formation porosity by 13.8% and if ε_1=0.2, R=10 μm and δ=200 nm we get 32.5%.

The consolidation process can be used as a primary treatment for the near-wellbore area adjacent to perforations to

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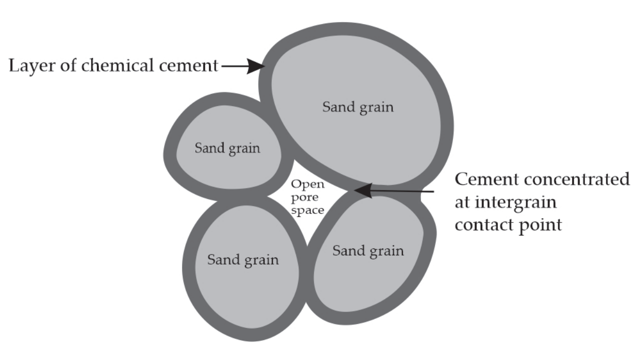

Fig. Chemical Sand Consolidation

stop sand production and formation fines migration.

Some of the new technologies of sand consolidation are:

1. Chemical Consolidation: Chemical consolidation involves the use of chemicals to bind sand particles together, creating a stable formation. One of the newer chemical consolidation technologies is a resin-based system that can be pumped into the wellbore and cured with heat or UV light [4-17].

   a. Resin Consolidation: This method involves injecting a resin into the formation surrounding the wellbore. The resin consolidates the formation and prevents sand from migrating into the wellbore.

   b. Polymer Gels: These are gels that are injected into the formation surrounding the wellbore. The gels create a barrier that prevents sand from migrating into the wellbore.

   c. Chemical Sand Consolidation: This method involves injecting a chemical into the formation surrounding the wellbore. The chemical consolidates the formation and prevents sand from migrating into the wellbore.

   d. Foams: These are foams that are injected into the formation surrounding the wellbore. The foams create a barrier that prevents sand from migrating into the wellbore.
2. Electromagnetic Consolidation: Electromagnetic consolidation uses a high-frequency electric field to create a strong bonding force between sand grains. This technology has the advantage of being able to consolidate sands without the use of chemicals, reducing the environmental impact.
3. Microbial Consolidation: Microbial consolidation involves the use of bacteria to create a natural binding agent that holds sand grains together [18]. This technology has the advantage of being environmentally friendly and can be used in remote locations.
4. Nanoparticle Consolidation: Nanoparticle consolidation involves the use of tiny particles, usually less than 100 nanometers in size, to bind sand grains together [19-24]. This technology has the potential to create stronger formations than traditional chemical methods.

Resin Consolidation

If the sand in the formation is unconsolidated, individual grains of sand may move along with the fluid and enter the wellbore through one or more perforations of casing. Sand particles in the wellbore may build up and prevent production of fluids from the well and sand particles in produced fluids may cause erosion of the well equipment. Therefore, it is necessary to prevent sand particle movement into the wellbore. Although various sand control techniques exist, in some wells it has been found that it is preferable to form a consolidated, permeable area of particles outside the perforations. This area is created by injecting liquid resin solutions through the perforations, injecting a fluid immiscible with the resin solution to decrease the resin saturation of the sand around the perforations, and polymerizing or allowing the resin to polymerize under conditions that the sand will be permeable [4]. For sand to be permeable, the resin solution must not completely fill the pore spaces of the rock, but it should bridge between grains of the formation and serve as an adhesive between the grains. The fluids entering the well can then flow through the artificially consolidated region and enter the well. In many wells, particularly where the well has produced sand before the resin treatment, it is preferable to pre-pack the near-wellbore region outside the perforations by injecting a slurry of clean, sized sand grains or synthetic grains. Polymerization of resins is caused by catalysts or curing agents. Catalysts greatly accelerate the rate of polymerization, but do not participate in the reaction. Curing agents react with a component of the resin to form a polymer. Sand consolidation with resins has been practiced for many years. The problem of diverting resin into each perforation has been approached in recent years by use of «gas generators» placed in the wellbore in proximity to the resin. U.S. Patent No. 4936385 [11] discloses igniting a propellant to generate gas pressure which rapidly forces the consolidating fluid through the perforations and into the subterranean formation.

In the patent [11, 12] the authors proposed a method for diverting resins and other treating fluids which used for sand control in wells drilled through unconsolidated subterranean formations. Explosives placed in the wellbore in proximity to the treating solutions operate to force solutions through all perforations in the well casing and allow sand-free production of fluids through the well.

Methods are provided for chemically consolidating subterranean formations around wells using resins. Resins are forced into the formations by high pressures instantaneously applied when perforations are formed in casing in wells or when pressures are released from tubing in wells [13]. Perforating, explosives or gas generators may be used in addition to the high pressures for driving resins into formations. The resins are polymerized to form permeable consolidated zones around wells.

In order to control the production of sand in oil reservoirs as a consolidation agent, phenol formaldehyde resin, urea formaldehyde resin and modified urea formaldehyde resin have been selected in the study [14]. The cores have been taken from the sand provided from the oil fields of the southern parts of Iran, which has a mean absolute permeability of 500-600 mD and a mean porosity of 15-20 %, combined with various proportions of each resin. Permeability, porosity and compressive strength measurements are performed on the core samples. The findings show that modified urea-formaldehyde resins are more suitable than the other two types of resins for consolidation. Compressive strength ranged from 3100 to 4150 psi, permeability from

980 to 6823 mD, and porosity from 8 to 98% for consolidated sand samples of this resin.

Polymer gels for sand control

In [5], a chemical method based on the use of polyacrylamide/chromium triacetate hydrogels was proposed for studying sand production in a synthetic sand packing system. Experiments showed that 0.5 pore volume of hydrogel injected into the sand pack improved the compressive strength of the sand pack up to 30x. It was also found that increasing the crosslinker and polymer concentrations had a positive effect on the compressive strength of the sandpack. The most significant effect was observed with crosslinker concentration (48 psi). The hydrogel with a higher value of crosslinker was able to maintain its viscoelastic properties against elongation. The maximum elongation was 122% for a crosslinker/polymer weight ratio of 0.5. Hydrogel stability is negatively affected by the presence of salts, especially divalent cations.

In the studies [6-8], in order to control sand production, the hydrogel injected as a chemical method have been used for the formation strength as a new method. Hydrogels were prepared from Acrylamido Propyl Sulfonated Acid as polymers and chromium (III) acetate as a crosslinker, ensuring their injectivity ability were used for the consolidation of sand in the reservoir. The results showed that the compressive strength increased about 20 times after injection of 1 pv hydrogel. In addition, the hydrogel injection decreased the sand production by 90%. In addition, the water permeability of sand after injection of the polymer gel decreased by 77 times, and oil permeability by 4 times. Due to the severe reduction in water permeability of the sand packed, hydrogel with double efficiency can be used to reduce the water production and control the sand production in oil and gas reservoirs.

Study [9] examined the performance of preformed dual-polymerized nanocomposite hydrogels (PNCHs) consisting of acrylamide, 2-acrylamide-2-methylpropanesulphonic acid, maleic acid, and acrylic acid in sand control. Furthermore, the effects of ferrous (PNCH 1), silica (PNCH 2) and bentonite (PNCH 3) nanoparticles on the PNCH structure were investigated. The results of the equilibrium swelling ratio (ESR) studies in distilled and formation water at ambient temperature for PNCHs (1), (2), and (3) were (13.9, 4.55), (15.45, 6.35), and (12.9, 4.8), also at reservoir temperatures ESR results were reported (78, 17.5), (89, 13), and (70, 12.9), respectively. According to the results of strain-sweeping tests, the PNCH structures may exhibit viscoelastic behavior with maximum Young's moduli of 29000, 8430, and 10800, and critical strains of 10, 19.3, and 10.8 %, respectively. The compressive strength test showed that the addition of 0.5 pore volume of 1 weight percent PNCH to the sand pack increased its strength by 980%.

In order to overcome sand production in oil reservoirs, a Co [AMAMPS-MALEIC-AAC]/PEI-MBA nanocomposite hydrogel with superior viscoelastic properties and double crosslinking was designed and synthesized [10]. In order to predict the effectiveness and performance of the produced nanocomposite in the harsh Iranian reservoirs, swelling, rheology and morphology tests were performed.

Based on the results obtained, at ambient temperature (25 °C, during injection) and reservoir temperature (90 °C, placed in porous medium), the maximum swelling ratios were 8.5 and 94 in distilled water, and 5.4 and 10.8 in formation water, respectively. The thermal stability of the sample up to 90°C with less than 0.6 wt% degradation was also confirmed according to the results of the thermal stability test. Results from strain-sweeping, frequency-sweeping, and stress-strain testing show a robust, 3D, and viscoelastic structure up to 100% strain and 100 Hz frequency. The maximum storage modulus is 27000 Pa when tested at 1Hz constant strain, and 18000 Pa when tested at 1 percent constant strain. Stress-strain tests showed that ultimate tensile strength was 4630 Pascal.

Chemical Sand Consolidation

As shown in a review article [19], chemical sand consolidation methods involve the injection of chemical materials (for example, furan resin and silicate non-polymer materials) into unconsolidated sandstone reservoirs to prevent sand production using fluids produced from hydrocarbon reservoirs. Injection of chemistries, primarily polymers, binds sand grains, resulting in greater compressive strength of stone. Therefore, fewer sand particles are carried in the produced fluids. However, by reducing the permeability of the rock, the effect of this bonding can negatively impact formation productivity.

The results from chemical sand consolidation treatments were presented in [25]. Chemical sand consolidation consists of two main components, resin and hardener. The consolidation fluid along with a pre-flush and an over-flush have typically been pumped into the well using production tubing. This sand control method has been proven to be relatively low in cost compared to other sand control techniques and the treatment can be performed in a relatively short period of time.

In [26] a catalyst is injected into the near wellbore region to active the sands and after that, the metal layer deposits spontaneously on the sand grains by injecting several aqueous solutions of metal salts including a chemical reducing agent. The electroless consolidation of formation sand with the catalytic plating of nickel from aqueous solution provides a flexible alternative to «plastic» or resin sand consolidation in certain cases. A shut-in period (required for resin curing) is not needed, stronger bonding is achieved, and the consolidation is suitable for exposure to temperatures far beyond the range of plastic sand consolidations.

The chemical sand consolidation treatment from the view of an oil company and the full lifecycle of the application from concept selection to the finalized procedure, taking into account both technical and operational considerations were studied in [27]. A single chemical recipe optimized for all of the reservoirs was achieved, yielding an unconfined compressive strength (UCS) of at least 500 psi while retaining a permeability of 40%.

The patent [11] provides a method of consolidating an incompetent subterrnean formation. An acid curable resin consolidating fluid is positioned within casing in a wellbore in the vicinity of perforations through the casing. A gas generating charge positioned within the casing then is ignited to generate gas pressure which rapidly forces the consolidating fluid through the perforations and into the subterranean formation while substantially simultaneously catalyzing the resin composition. The consolidating fluid is caused to rapidly harden to consolidate the formation in the vicinity of the perforation without any significant permeability loss.

Foams for sand consolidation

In [16], a novel foam amino resin system for oilfield sand control based on chemical consolidation is reported. Excellent foam properties and high compatibility with formation fluids are provided. The foam amino resin sand consolidation system was optimized and studied. A comprehensive evaluation of the sand consolidation performance of the foam amino resin system was performed. Optimal conditions are: consolidated core compressive strength, 6.28 MPa; curing time, 12 h; curing temperature, 60 °C.

Metal foam is recently being applied in down-hole sand control. The open pore metal foam [28] is wrapped around a cylindrical geometry perforated base pipe and the effects of pore size and relative density on the metal foam mechanical properties and the relationship between the pore size and the sand control size have been studied in [29]. The paper compares the sand control characteristics of metal foam with two different conventional mechanical sand control screens supplied by manufactory, under similar conditions, loads, and formation sand. The metal foam-based sand control screen improves the sand retention, and reduces the flow resistance by 16.6%.

According to energy-conservation equations, mass-conservation equations, and momentum-conservation equations, a mathematical model for sand cleanout with foam fluid was established that considers the heat transfer between foam in the annulus and foam in the tubing [30]. Site applications show that sand cleanout with foam fluid can prevent fluid leakage effectively. It can avoid damage of sealing agents and reduce pollution. The average relative error and standard deviation between model and field data on injection pressure are 0.43 and 2.55%, respectively, which proves the validation of the mathematical model.

Electromagnetic Consolidation

Electromagnetic waves (EM) can be used to remove the skin damage caused by fluid in a near wellbore region. In addition, EM waves can remove and damage caused by fines migration by creating new fractures and thus increasing permeability in the near wellbore region. The patent [31] describes methods and systems for removing near wellbore damage in a hydrocarbon reservoir. One method includes position an antenna inside a wellbore in a location corresponding to a formation where near wellbore damage occurs; wherein the wellbore extends from a surface of a hydrocarbon reservoir downward into the subterranean structure of the hydrocarbon reservoir; transmitting an electromagnetic (EM) wave to the antenna; and irradiating, from the antenna, at least a portion of the EM wave at the formation, wherein the portion of the EM wave removes the near wellbore damage at the formation.

In [32] the effect of high voltage and low-voltage pulsed electromagnetic fields in the technologies of powder consolidation was considered. The experimental devices of spark-plasma sintering, flash-sintering, high voltage consolidation and magnetic-pulse compaction were used for the production of advanced materials from metal powders, ceramic and composite powders. Experimental results to consolidation metal powders, ceramic and composites powders by electromagnetic methods presage fruitful results which can be used in particularly for sand control in oil and gas industry.

The effect of nanoparticles on sand production

In the review article [19], the chemical agents used for sand consolidation are discussed and a detailed evaluation between these agents is presented to serve as a screening tool that can assist in the selection of chemical sand consolidation agent, which can help optimize the sand control performance. In addition, the review highlights the advancements in chemical sanding processes, including the use of different types of polymers and the use of nanoparticles, and tracks the impact of improved sanding efficiency and production output. Based on this review, it is highly recommended that the nanoparticle related materials be applied as sand consolidating agents due to the ability to produce acceptable rock strength with insignificant reduction in rock permeability.

A new consolidant (nano-SiO_2 in urea-formaldehyde) for controlling sand grain migration and in-situ consolidation was proposed in the study [20]. In the absence and presence of hydrocarbon, the ability of this nanoparticle induced chemical solution to bind the sand grains together at their contact point, its mechanical properties and its resistance to water have been studied. With a small reduction in permeability, a high compressive strength (42000 psi) was obtained. In order to evaluate the durability of the consolidation, the effect of pressure drop and flow rate on the consolidation was studied to determine the critical flow rate at which the sand particle begins to separate from the consolidated.

In [21] the effect of brine salinity, cation type, pH, and produced sand on zeta potential (ZP) measurements with and without the presence of silica nanoparticles is investigated. The results show that the use of silica nanoparticles with high pH helps in preventing sand production. Nanoparticles can be active as a coating on sand grains and prevent sand segregation during water flooding. Divalent cations have been found to acquire a more substantial impact on neutralizing the negative charge of the sand particles than monovalent cations at the same concentration and pH conditions at 25 °C.

In experimental researches [22, 23], silica nanoparticles were used to formulate a smart nanofluid containing smart water and nanoparticles for sand control. The authors concluded that nanoparticles cover the rock leading to preventing the migration of mineral separated from the surface. In fact, silica nanoparticles are in the form of charged particles, which have hydrophilic chains (OH), and can convert the oil-wet property of the rock to water-wet. Therefore, this alternation increases oil production coupled with a decrease in sand production as a result of less the surface contact with the smart water and leaching the rock.

Kalgaonkar et al. [24] conducted research on the consolidation of sand grains using positive-charged colloidal nanoparticles, consisting of cationic modifiers and ionic strength modifiers, which is placed as a single pill at bottom-hole. As this pill forms a thin layer of tough gel around the sands at reservoir temperature, it cements the particles together, and does not significantly reduce the formation porosity and permeability to ensure easy flow of produced hydrocarbons or injected water. The authors proposed the following sand consolidation mechanism. The cationic nanoparticles are initially in low viscosity emulsion form, then with the addition of an activator it becomes a hard composition, where the positive-charged nanoparticles are placed around the sands due to their negative charge as a result of the electrostatic forces. Furthermore, the repulsive force among the positive charges will maintain the composition viscosity low and prevent premature hardening of the composition to allow sufficient time to reach the bottom-hole, and this repulsion also prevents the nanoparticles from agglomeration [33].

The results of a study on the displacement of residual oil on homogeneous quartz sandstone using nanofluids were presented in [34]. In addition, a new method was introduced for increasing oil production by using nanoparticles in the reservoir.

In [35-37] Zeta potential and turbidity analyses have been utilized as quantified tools to examine the effect of nanoparticles (NP) on the interactions of colloidal particles with the medium surface. It was shown that MgO NP can modify the zeta potential of the medium and in turn remarkably retain the colloidal fines in the presence of very low concentration of both monovalent and divalent salts; therefore, fines migration induced during low salinity conditions can be prevented. It was found that the MgO NP-treated medium tends to retain around 97% of the in-situ fine particles at very alkaline conditions.

Microbial Consolidation

Microbially Induced Carbonate Precipitation (MICP) is a promising technology for the consolidation of sandy soils, soil amelioration, concrete cracking repair, and rehabilitation of contaminated sites. In paper [38], on basis of critical review of microbial sources of hardened sand, models used for prediction of sand hardening process and factors controlling MICP process, current problems of MICP were analyzed and future research directions, ideas and suggestions for further study and application of MICP were given.

The results of a study using natural microbial biological processes to build a cemented soil matrix in initially loose, collapsible sand are presented in [39]. The microorganism Bacillus pasteurii, an aerobic bacterium ubiquitous in natural soil deposits, was used to achieve microbially induced calcite precipitation (MICP). In a liquid growth medium supplemented with urea and a dissolved calcium source, the microbes were introduced to the sand samples. The sample was then subjected to cementing treatments to increase the degree of cementing of the sand particle matrix.

The results of both MICP- and gypsum-cemented specimens were assessed nondestructively by measuring the shear wave velocity with bender elements. A series of isotropically consolidated undrained compression (CIUC) triaxial tests indicate the MICP-treated specimens exhibit a noncollapse strain softening shear behavior, with a higher initial shear stiffness and ultimate shear capacity than untreated loose specimens. This behavior is similar to that of the gypsum-cemented specimens, which represent typical cemented sand behavior. SEM microscopy verified formation of a cemented sand matrix with a concentration of precipitated calcite forming bonds at particle-particle contacts. X-ray compositional mapping confirmed that the observed cement bonds were comprised of calcite. These are just a few examples of emerging sand consolidation technologies. As the industry evolves, we can expect more innovative solutions emerge to help stabilize loose sand formations and prevent sand production during oil and gas production.

The process of chemical consolidation typically involves the following steps:

1. Preparation: The wellbore is prepared for the injection of the resin or chemical. This may involve cleaning the wellbore, perforating the casing, and installing injection equipment.
2. Injection: The resin or chemical is injected into the formation surrounding the wellbore. The injection pressure is carefully controlled to ensure that the resin or chemical is distributed evenly throughout the formation.
3. Curing: The resin or chemical is allowed to cure or harden, which typically takes several hours to several days. During this time, the sand particles in the formation are bound together, creating a consolidated zone that prevents sand from entering the wellbore.
4. Cleanup: After the resin or chemical has cured, the wellbore is cleaned and any excess material is removed.

Several factors determine whether chemical consolidation is a suitable sand control method for a well. Here are some of the key factors to consider:

1. Formation characteristics: The characteristics of the formation surrounding the wellbore are critical in determining whether chemical consolidation is a suitable sand control method. The formation must be cohesive enough to allow the resin or chemical to bond the sand particles together effectively.
2. Sand production rate: Chemical consolidation is typically effective for wells with low to moderate sand production rates. Wells with high sand production rates may require different sand control methods.
3. Well configuration: The configuration of the wellbore, including its angle and length, can impact the effectiveness of chemical consolidation. For example, deviated wells may require more resin or chemical to ensure even distribution throughout the formation.
4. Production goals: The production goals for the well, including the desired flow rate and the expected lifespan of the well, can impact the selection of a sand control method. For example, if the well is expected to produce for a long period of time, a more durable sand control method may be required.
5. Cost considerations: The cost of chemical consolidation can vary depending on the size of the well and the amount of resin or chemical required. Operators should consider the cost of chemical consolidation in relation to the expected benefits, including improved well productivity and reduced equipment damage.

Sand consolidation is an effective method for controlling sand production. The chemicals injected into the formation bond the sand grains together, creating a solid mass that prevents sand production.

Sand consolidation can provide long-term sand control. The bonded sand can remain in place for years, providing a reliable solution for sand control. Sand consolidation is compatible with other sand control methods such as gravel packing and screens. Sand consolidation can be cost-effective when compared to other sand control methods. The process involves injecting chemicals into the formation, which is less expensive than installing screens or gravel. Sand consolidation is only suitable for certain types of formations. It may not be effective in formations with high permeability or where the sand is too fine. The injection of chemicals into the formation can cause damage to the formation. This damage can reduce the productivity of the well and affect the reservoir. The success of sand consolidation depends on various factors such as the type of chemicals used, the injection rate, and the formation properties. There is uncertainty about the effectiveness of sand consolidation, which can be a significant drawback. The chemicals used in sand consolidation can be harmful to the environment. The disposal of these chemicals can also be a challenge.

Sand consolidation is an effective method for sand control, but it has its pros and cons. It is essential to consider the specific formation properties and other factors before deciding to use sand consolidation for sand control.

Halliburton SandTrap ABC

Halliburton SandTrap ABC is a chemical sand consolidation system that is designed to improve sand control in oil and gas wells [40, 41].

The SandTrap ABC system involves injecting a specially formulated resin into the formation to consolidate the sand grains and create a strong, stable, permeable mass. The resin is injected using a specially designed pump and is activated by a chemical catalyst to quickly harden and set in place.

The SandTrap ABC system is typically used in unconsolidated or poorly consolidated sandstone formations where sand production is a major issue. The system can help to minimize or eliminate sand production and improve well productivity by providing a stable, permeable barrier that allows hydrocarbons to flow freely while preventing sand from entering the wellbore.

Halliburton has reported success using SandTrap in a variety of applications, including high-rate gas wells, wells with unconsolidated sand, and wells with high levels of fines and solids. The company has also reported that the system is compatible with a range of other completion fluids and treatments, which can help to optimize well performance and reduce operational costs. However, as with any sand control system, the performance of SandTrap can vary depending on the specific well conditions, so it is important to consult with technical experts and conduct thorough testing and evaluation before selecting and implementing the system.

SandTrap ABC uses a unique filter media called Accuflux™ to provide efficient sand control in oil and gas wells. Here's how it works:

Accuflux™ is a sintered metal filter media made from high-strength, corrosion-resistant alloys such as Inconel and Hastelloy. The media is designed with a precise pore size distribution to ensure optimal sand retention while maintaining high flow rates. The pore size can be tailored to the specific sand size distribution of the reservoir to maximize sand control efficiency.

The filter media is wrapped around a central mandrel to create a filter element, which can be easily installed in the wellbore using conventional completion techniques. The filter elements can be stacked and connected to form a complete sand control assembly.

During production, fluid flows through the filter media, which captures and retains sand particles while allowing clean fluid to pass through. The filter media is designed to provide uniform flow distribution across the entire filter element, which helps to prevent localized sand accumulation and flow restriction. This helps to extend the life of the filter media and reduce the risk of failure.

SandTrap ABC's filter media is also designed to be easily cleaned and maintained. The filter elements can be backwashed with clean fluid to remove any accumulated sand particles, which helps to restore the filter media to its original performance level. This can be done remotely using SandTrap ABC's flow control system, without the need for costly workovers.

The cost of Halliburton SandTrap ABC (Advanced Bypass and Control) compared to other sand control methods depends on several factors, including the specific well and reservoir conditions, the type and size of the completion system, and the required maintenance and workover costs over the life of the well.

In general, SandTrap ABC can be more expensive than some traditional sand control methods, such as gravel packing or standalone screens, particularly for wells with challenging sand control conditions. This is because SandTrap ABC's flow control system and zonal isolation capabilities require additional equipment and infrastructure, which can add to the complexity of the completion design and installation.

However, SandTrap ABC's improved sand control performance and reduced risk of failure can provide significant cost savings over the life of the well, particularly in high-cost or high-risk environments. For example, SandTrap ABC can help to minimize the risk of sand production and associated equipment damage, which can result in costly workovers and downtime. It can also help to optimize production by allowing for more precise and effective reservoir management.

The cost-effectiveness of SandTrap ABC compared to other sand control methods will depend on the specific well and reservoir conditions, as well as the operator's production objectives and risk tolerance. Operators should carefully evaluate the costs and benefits of each sand control method and select the one that provides the best overall value for their specific situation.

Some examples of high-cost or high-risk environments where SandTrap ABC can be more cost-effective compared to other sand control methods:

1. Deepwater wells: Deepwater wells are typically more expensive to drill and complete than onshore or shallow water wells, due to the complexity of the operations and the need for specialized equipment and infrastructure. Sand production can be a significant risk in deepwater wells, as it can lead to erosion and damage to subsea equipment, which can be costly to repair or replace. SandTrap ABC can help to mitigate this risk by providing reliable sand control performance and reducing the need for costly workovers.
2. High-pressure/high-temperature (HP/HT) wells: HP/HT wells are characterized by extreme reservoir conditions, such as high temperatures and pressures, which can pose significant challenges for sand control. Traditional sand control methods may be less effective or may require frequent maintenance and workovers, which can be expensive and time-consuming. SandTrap ABC's flow control system and zonal isolation capabilities can help to provide more reliable and efficient sand control in these challenging environments.

3. Horizontal and multilateral wells: Horizontal and multilateral wells are often used to maximize the production from a reservoir by increasing the contact area between the wellbore and the reservoir. However, these wells can also be more prone to sand production, particularly in unconsolidated formations. SandTrap ABC's flow control system and filter media design can help to provide efficient sand control in these wells, while minimizing the risk of flow restriction and premature failure.
4. Mature fields: Mature fields are often characterized by declining production rates and increased water or gas production, which can exacerbate sand production issues. Traditional sand control methods may be less effective in these fields, particularly if the reservoir conditions have changed over time. SandTrap ABC's flexible design and customizable features can help to provide tailored sand control solutions for these complex and challenging environments.

Some ways in which SandTrap ABC's flow control system compares to other sand control systems:

1. Improved sand retention: SandTrap ABC's flow control system is designed to prevent the accumulation of sand in the filter media, which can lead to flow restriction and premature failure. Traditional sand control systems, such as gravel packing or standalone screens, may be less effective in preventing sand production, particularly in challenging reservoir conditions.
2. Higher flow rates: SandTrap ABC's flow control system allows for high flow rates while maintaining effective sand control performance. This can help to maximize production rates while minimizing sand production and equipment damage. Traditional sand control systems may be more restrictive to flow, which can lead to reduced production rates and flow-related issues.
3. Easy maintenance and cleaning: SandTrap ABC's flow control system allows for easy cleaning and maintenance of the filter media and flow control devices. The filter elements can be backwashed with clean fluid to remove any accumulated sand particles, which helps to restore the filter media to its original performance level. This can be done remotely using SandTrap ABC's flow control system, without the need for costly workovers. Traditional sand control systems may require more frequent maintenance and workovers to maintain their sand control performance.
4. Integrated zonal isolation capabilities: SandTrap ABC's flow control system is integrated with inflatable packers, allowing for precise control of fluid flow and sand retention in each isolated zone. The packers can be inflated and deflated remotely, reducing the need for costly workovers. This can help to optimize production and improve reservoir management. Traditional sand control systems may not have this level of zonal isolation capabilities.

Overall, SandTrap ABC's flow control system offers a reliable and effective solution for sand control in oil and gas wells, with the added benefits of improved sand retention, higher flow rates, easy maintenance and cleaning, and integrated zonal isolation capabilities. While traditional sand control systems may still be effective in certain well and reservoir conditions, SandTrap ABC's flow control system can provide a cost-effective and efficient solution in many challenging and complex environments.

Champion SC2020

Champion SC2020 is a chemical sand consolidation system developed by Nalco Champion, which is a subsidiary of Ecolab [42, 43]. This system is designed to stabilize loose or unconsolidated sand formations, improving sand control and reducing the amount of sand production in oil and gas wells.

The Champion SC2020 system involves injecting a resin-based solution into the sand formation to consolidate the grains and create a strong, stable, and permeable mass. The resin is activated by a chemical catalyst and rapidly hardens to form a solid mass, which helps to hold the sand grains together and prevent sand migration.

The Champion SC2020 system can be used in a variety of well completions, including open-hole, cased-hole, and gravel pack applications. It is particularly effective in formations where sand production is high or where the sand grains are poorly consolidated, such as in some unconsolidated sandstone formations.

In general, chemical sand consolidation systems like Champion SC2020 have been used successfully in many oil and gas fields around the world to improve sand control and well productivity. The effectiveness of these systems can depend on a variety of factors, including the formation properties, wellbore geometry, and completion design. Therefore, it is important to evaluate the specific conditions of each well before selecting a sand control solution and to monitor the performance of the system during and after the treatment.

Nalco Champion has reported success using the Champion SC2020 system in a variety of applications, including cased-hole and open-hole completions, and in both onshore and offshore wells. The company has also reported that the system is compatible with a range of other completion fluids and treatments, which can help to optimize well performance and reduce operational costs. However, as with any sand control system, the performance of Champion SC2020 can vary depending on the specific well conditions, so it is important to consult with technical experts and conduct thorough testing and evaluation before selecting and implementing the system.

The paper [44] describes a method for consolidating sand and repairing channels using a resin system consisting of a resin (a mixture of UF, MF elastomers and a suitable plasticizer) and a hardener (a mixture of two mild Lewis acids). Cure time is controlled by the hardener. The plasticizer's role is to make the otherwise brittle UF-MF resin flexible and impact resistant. If necessary, a special additive is used to improve the surface bond between sand and resin. The compressive strength of the consolidated sand and shale is extremely high for withstanding the overburden pressure and mechanical impact during drilling.

The study [45] presents the results of laboratory development and field testing of a new water-based resin-consolidation system applicable for proppant flowback and sand consolidation as well as field trials for proppant-flowback applications. This new system benefits from effective and efficient treatment of significantly longer intervals and improved health, safety, security, and environmental compatibility (HSSE) compared to conventional consolidation systems.

Talaghat et al. [46] presented the results of testing six types of resins (two types of epoxy resins, three types of phenol formaldehyde resins and a single type of acrylic resin) as consolidating agent in the Asmari oil wells of the Ahwaz and Mansoori oil fields. The obtained experimental data showed that only for a given type of phenol–formaldehyde resins, the permeability and porosity of the core samples are retained in acceptable values and their compressive strength become greater than 3000 psi, i.e., the modified phenol–formaldehyde resin is suitable as consolidating agent in considered oil field formations.

The review [4] provides an overview of laboratory and field studies of chemical controls against sand mining. This article presents some of the chemical agents used and more common laboratory tests to evaluate the chemical characteristics of sand consolidation. In addition, the results of field operations and injection of chemicals into the desired formation are also reported. These results show that the chemical sand consolidation is more effective in newly perforated wells which have no sand production experience and have a production history of less than two years. It was concluded that the main challenges in applying this method are permeability and capillary force reduction around the wellbore and selective injection into the targeted formation layers.

The aim of the review [8] is to summarize the studies on the control of sand production in oil reservoirs in a comprehensive guide for the researcher. In this study, various methods for the control and prevention of sand production in oil wells are presented and their advantages and performance are evaluated in tabular form. The use of chemical procedures is considered to be more efficient in counteracting the production and migration of sand. Various chemicals and polymers have been proposed for this purpose. These chemicals should increase the consolidation of the formation rock while not reducing its permeability.

Lubrizol SandAid

Sand Aid is a chemical sand consolidation system developed by Lubrizol, a specialty chemical company that offers a range of solutions for the oil and gas industry [47]. The Sand Aid system is designed to improve sand control and reduce sand production in oil and gas wells.

The Sand Aid system involves injecting a specially formulated resin into the formation to consolidate the sand grains and create a strong, stable, permeable mass. The resin is activated by a chemical catalyst and quickly hardens to form a solid mass, which helps to hold the sand grains together and prevent sand migration.

The Sand Aid system can be used in a variety of well completions, including open-hole, cased-hole, and gravel pack applications. It is particularly effective in formations where sand production is high or where the sand grains are poorly consolidated, such as in some unconsolidated sandstone formations.

Baker Hughes Sand Stop Aqua

Sand Stop Aqua Technology is a patented technology developed by Baker Hughes, a leading energy technology company, to prevent sand production and enhance oil and gas production in wells [48, 49]. The technology is specifically designed to address the challenges associated with sand production in offshore and onshore wells.

The Sand Stop Aqua Technology system consists of a blend of water, polymers, and other additives that form a gel-like substance when mixed. This gel is injected into the wellbore to form a filter cake, which helps to stabilize the formation and prevent sand particles from entering the wellbore. The filter cake can also be designed to be self-healing, which means that any cracks or breaks that occur can be quickly repaired, ensuring continuous protection against sand production.

When Sand Stop Aqua is pumped into the wellbore, it forms a strong, stable bond with the surrounding formation, helping to prevent sand from entering the wellbore during production. This solution has been designed to be effective in a wide range of reservoir conditions, including high-temperature, high-pressure, and high-salinity environments.

One of the key advantages of Sand Stop Aqua is its high flow capacity. This allows for greater production rates and reduced pressure drop across the proppant pack, improving the overall efficiency of the well. Additionally, the solution is environmentally friendly and does not contain any harmful chemicals.

In addition to preventing sand production, Sand Stop Aqua Technology can also enhance oil and gas production by increasing the permeability of the reservoir. The technology is also environmentally friendly, as it is non-toxic and biodegradable, making it a safer and more sustainable solution for oil and gas production.

Sand Stop Aqua technology is a relatively new approach to sand control, and it offers several advantages over traditional sand control methods. Here are some key differences to consider:

1. No gravel packing required: Gravel packing is a common method for sand control, but it can be time-consuming and expensive. Sand Stop Aqua technology does not require gravel packing, which can save time and money.
2. Improved well productivity: Sand Stop Aqua technology is designed to prevent sand from entering the wellbore, which can improve well productivity by reducing sand-induced damage and plugging.
3. Compatibility with horizontal and deviated wells: Sand Stop Aqua technology is designed to be compatible with a range of well types, including horizontal and deviated wells. This makes it a versatile solution for a variety of well configurations.
4. Reduced environmental impact: Gravel packing can create environmental concerns due to the need to transport and dispose of large amounts of sand and gravel. Sand Stop Aqua technology does not require gravel packing, which can reduce the environmental impact of sand control operations.
5. Limited track record: Sand Stop Aqua technology is a relatively new approach to sand control, and its long-term performance and reliability have yet to be fully established.

There are several examples of Sand Stop Aqua technology being used successfully in the field. Here are a few case studies:

1. North Sea: In a North Sea well, Sand Stop Aqua

technology was used to prevent sand production in a horizontal well with a high water cut. The technology was successful in preventing sand production and improving well productivity, with no signs of sand production observed during the first year of production.
2. Gulf of Mexico: In a Gulf of Mexico well, Sand Stop Aqua technology was used to prevent sand production in a deviated well with a high sand content. The technology was successful in preventing sand production and improving well productivity, with no signs of sand production observed during the first six months of production.
3. Middle East: In a Middle East well, Sand Stop Aqua technology was used to prevent sand production in a horizontal well with a high sand content. The technology was successful in preventing sand production and improving well productivity, with no signs of sand production observed during the first year of production.
4. South America: In a South American well, Sand Stop Aqua technology was used to prevent sand production in a horizontal well with a high sand content. The technology was successful in preventing sand production and improving well productivity, with no signs of sand production observed during the first six months of production.

While Sand Stop Aqua technology offers several benefits for sand control in oil and gas wells, there are also some limitations to consider:

1. Limited track record: Sand Stop Aqua technology is a relatively new approach to sand control, and its long-term performance and reliability have yet to be fully established.
2. Limited application range: Sand Stop Aqua technology is designed for use in wells with relatively low sand production rates. If the sand production rate is too high, the technology may not be effective.
3. Limited compatibility with certain fluids: Sand Stop Aqua technology is not compatible with all types of fluids. For example, it may not be effective in wells producing heavy oil or high-viscosity fluids.
4. Possible impact on well productivity: While Sand Stop Aqua technology is designed to prevent sand from entering the wellbore, it may also reduce the flow rate of hydrocarbons in some cases.
5. Additional cost: Sand Stop Aqua technology represents an additional cost compared to traditional sand control methods, which may be a limiting factor for some operators.

Sand management

Sand management refers to the practices and techniques used to control and manage the production of sand in oil and gas wells [50-58]. During the production of hydrocarbons, sand can be produced along with the oil and gas, which can cause significant problems such as wellbore erosion, equipment damage, and decreased production rates.

Sand management is a critical aspect of oil and gas production, and several new technologies have been developed to improve sand management in the industry. Here are some examples:

1. Machine learning and Artificial intelligence: machine learning and AI technologies have been used to build predictive models which can identify potential sand production issues before they become major problems. These models use real-time data from sensors to make predictions about sand production and allow operators to take proactive measures to manage sand production.
2. Autonomous sand monitoring systems: Autonomous sand monitoring systems use sensors and data analytics to monitor sand production in real-time. These systems can detect sand production events and alert operators to take corrective action.
3. Sand control measures: Sand control measures are designed for preventing sand entering the well and production facilities. These measures include screens, gravel packs, and chemical treatments.
4. Chemical sand control: Chemical sand control technologies involve injecting chemicals into the formation to create a permeable barrier that blocks sand production. New chemical sand control formulations have been developed that are more effective and environmentally friendly than traditional chemical treatments.
5. Multilateral sand screens: Multilateral sand screens are screens that are installed in multiple wellbores from a single wellhead. These screens allow for better sand control and can help increase production rates.
6. Advanced sand screen materials: Advanced sand screen materials, such as ceramic or metal-matrix composites, have been developed that are more durable and resistant to erosion than traditional sand screen materials. These screens can improve sand management by reducing screen failures and maintenance requirements.

Sand production problems encountered during drilling and production operations are thoroughly reviewed in [59]. The causes and mechanisms of sand production, the factors influencing the sand production capacity (i.e., the causes of sand production), and the remedies are discussed.

The mechanical properties log provides a quantitative means to identify sands that are strong enough to produce oil and gas without any form of sand control. The method correlates the field strength with the dynamic Young's modulus calculated from the sound and density logs [54].

The book [55] devoted to the sand production problems in the development of unconsolidated sand reservoirs and analyzed novel technical solutions and improvements to sand management issues.

The choice of a suitable method to prevent formation sand production is dependent on different reservoir parameters and the choice of the best sand control method is the result of a systematic investigation. Sand production factors and their impact, with emphasis on sand forecasting to determine sand production probability from reservoir, and then proper preventive implementation of sand control procedure are presented in [60]. The combination of the two is presented as an intelligent control framework that can be used to manage sand production. The purpose of the study [61] was to develop a flowchart guide that could potentially be used in practice when considering optimal sand control methods and implementation of completion technologies in sand producing wells. The flow chart could also serve as a tool during the decision-making process where sand control is deemed necessary. Distinct reservoir data and key parameters were incorporated into the designing of the flow chart. This paper predominantly focused on two of the most common techniques used currently in practice; sand screens and gravel pack.

The purpose of the review [8] is to consolidate research on the control of sand production in oil reservoirs into a comprehensive guide for the researcher to compare different methods of chemical sand compaction. In this study, various methods for controlling and preventing sand production in oil wells were presented and their advantages and effectiveness were evaluated in tabular form.

Mechanical Sand Remediation Methods

Mechanical sand remediation methods are used to remove sand and other debris from oil and gas wells [62, 63]. These methods involve physical tools and techniques to clean the wellbore and ensure optimal production. Some of the most common mechanical sand remediation methods include:

1. Sand Cleanout Tools: Sand cleanout tools are designed to remove sand and other debris from the wellbore. These tools typically include a high-pressure jetting system that blasts the sand and debris from the well casing. Sand cleanout tools can be run on a wireline or coiled tubing, depending on the well's configuration.
2. Gravel Pack Systems: Gravel pack systems are used to prevent sand from entering the wellbore in the first place. These systems involve placing a layer of gravel around the well casing to create a filter that allows oil and gas to flow through but keeps sand out. Gravel pack systems can be installed during the initial completion of the well or as a remediation method later on.
3. Chemical Treatments: Chemical treatments can be used to dissolve or break up sand and other debris in the wellbore. These treatments often involve acids or other chemicals that can dissolve sand and other materials. However, chemical treatments can be expensive and may require additional remediation methods to remove the dissolved material from the well.
4. Jetting: Jetting involves using high-pressure water or air to remove sand and other debris from the well. Jetting can be an effective method for removing sand in shallow wells or for cleaning out small sections of the wellbore. However, jetting can also damage the well casing and may not be effective for larger wells or deeper sections of the wellbore.

Sand monitoring techniques

Machine learning

Machine learning is a powerful tool for sand control and management in the oil and gas industry [64-67]. By analyzing large volumes of data from various sources, machine learning algorithms can identify patterns and predict sand production and behavior, allowing operators to optimize their sand control strategies and improve well performance.

Some of the ways machine learning can be applied to sand control and management include:

1. Predicting sand production: Machine learning algorithms can analyze data from sensors and other sources to predict sand production rates and locations. This information can be used to optimize sand control strategies and prevent sand-related problems.
2. Identifying sand control failures: Machine learning algorithms can identify patterns in well data that indicate sand control failures, such as screen plugging or gravel pack failures. This information can be used to take proactive measures to prevent future failures.
3. Optimizing sand control treatments: Machine learning algorithms can analyze data from previous sand control treatments to identify the most effective treatment strategies for specific well conditions. This can help operators to optimize their sand control treatments and improve the success rate of these treatments.
4. Monitoring sand control performance: Machine learning algorithms can monitor sand control performance in real-time and identify potential problems before they escalate. This can help operators to take proactive measures to prevent equipment failures and sand-related production declines.

The paper [66] demonstrates the capability of machine learning algorithms in solving the problem of sand production from sands containing natural gas hydrates (NGH), which is considered to be a serious problem for commercialization. The commercial development of NGH reservoirs is hindered by the sand production problem. Complex mathematical assumptions are required for the conventional sand production prediction methods. Introducing machine learning to sand production prediction using data from laboratory experiments is the main contribution of this work. Four major machine learning algorithms have been selected, namely, K-Nearest Neighbor, Support Vector Regression, Boosting Tree, and Multi-Layer Perceptron. A sand production experiment was used to collect training data for machine learning. The experiment took into account both the geological parameters and the sand control effect. The main evaluation criteria were the mean absolute error and the coefficient of determination of the machine learning algorithms. The evaluation results showed that under the given conditions, the Boosting Tree algorithm provided the most accurate results, while the K-Nearest Neighbor algorithm provided the worst prediction. Support Vector Regression and Multi-Layer Perceptron could also be used to predict sand production as an ensemble prediction model. In order to improve the prediction performance of SVR, the tuning process showed that the Gaussian kernel was the appropriate kernel function. Furthermore, the best parameters for Boosting Tree and Multi-Layer Perceptron were recommended for accurately predicting sand production. This paper also included a case study that demonstrated the ability of machine learning to accurately predict sand production, especially under stable pressure conditions, by comparing the prediction results of the machine learning models and classical numerical simulation. By analyzing large volumes of data and identifying patterns and trends, machine learning algorithms can help operators to optimize their sand control strategies, prevent sand-related problems, and improve the performance of their wells.

SandView

SandView is a sand control monitoring and evaluation service offered by Schlumberger, a leading oilfield services company [64]. SandView uses acoustic sensors and proprietary algorithms to monitor sand production and flow in real-time during production operations. The system provides operators with valuable information about sand production rates, sand particle size distribution, and the location of sand accumulation within the wellbore.

SandView helps operators to optimize their sand control strategies and improve well performance by providing real-time data on sand production. By understanding the flow and behavior of sand in the wellbore, operators can adjust their production rates, optimize their sand control treatments, and take action to prevent sand-related problems such as equipment erosion and sand-induced production decline.

The SandView system is installed in the wellbore and is capable of providing continuous monitoring and analysis of sand production during production operations. The system is also designed to be compatible with other Schlumberger services, such as gravel pack design and sand control treatments, to provide a comprehensive sand management solution for operators.

Overall, SandView is a valuable tool for operators looking to optimize their sand control strategies and improve the performance of their wells. By providing real-time data on sand production and behavior, SandView helps operators to make informed decisions and take proactive measures to prevent sand-related problems.

AIQUM

AIQUM (Advanced Intelligent Quick Unmanned Machine) is a technology developed by Delft Dynamics that uses fiber optics to detect sand production in oil and gas wells [68, 69]. The system consists of a drone equipped with a fiber-optic sensor that is flown over the well to detect sand particles in the production stream.

The fiber-optic sensor is designed to be highly sensitive, able to detect even small amounts of sand particles in the production stream. As the drone flies over the well, the sensor records data that can be used to create a 3D map of the sand distribution in the well. This data can be used to identify areas where sand production is high, allowing operators to take action to prevent sand from entering the production stream.

One of the key advantages of the AIQUM system is its speed and efficiency. Traditional sand detection methods can be time-consuming and expensive, requiring manual inspection and analysis of production samples. With AIQUM, sand detection can be performed quickly and automatically, allowing operators to identify and respond to sand production issues more rapidly.

The AIQUM system is part of a broader trend in the oil and gas industry towards the use of automation and artificial intelligence to improve efficiency and reduce costs. As these technologies continue to evolve, we can expect to see even more innovative solutions emerge to help operators manage sand production and other production issues more effectively.

Sand production prediction models

Critical pressure gradient, erosion criteria, shear and tensile failure, critical plastic strain and critical drawdown pressure are the main mechanisms of sand production. Rock failure can occur when the effective minimum principal stress is equal to the tensile or shearing strength of the underlying rock, or a combination of them [70]. The mechanism responsible for particle removal after degradation during production is also thought to be these modes. Tensile failure refers to seepage forces on degraded sand particles in this case.

In cemented sands, shear failure can occur when some planes near the wellbore are subjected to higher stresses than they can withstand, and when combined with tensile cracking and high compressive stresses, it can lead to wellbore wall buckling [71].

In addition, in high-porosity sandstones, pore collapse can occur when effective hydrostatic stresses are increased by reservoir pressure reduction, resulting in sand production. Failure envelope compression yield cap can be used to capture plastic volumetric compression.

A tensile failure criterion for the collapse of the inner shell of perforated tunnels was proposed by Risnes and Bratli [72]. They also proposed sand criteria with respect to pressure gradients. A sand production model triggered by either shear or tensile failure was proposed by Morita et al [73].

Internal and surface erosion caused by dynamic seepage forces which release and transport sand particles. It can be caused by micro-mechanical effects of gas bubbles, water drops, etc. on the solid structure. The hydromechanical aspect of the sand production problem is studied and the basic framework of the mathematical modeling is established in [74]. In particular, the effects of pipe and surface erosion are studied. Mass balance and particle transport considerations as well as Darcy's law are applied. The findings show that surface erosion involves large changes in porosity and permeability near the free surface. To determine the constitutive parameters of the problem, experimentally measurable quantities such as the amount of produced solids or fluid discharge can be used in an inverse way. Using sand production experiments, Tronvoll et al. [75] showed that, in addition to radial flow, axial flow parallel to perforations is also significant in sand production and may lead to surface erosion of perforations. To consider axial flow conditions, Vardoulakis et al. in [76] extended their previous work [74]. They included Brinkman's extension of Darcy's law in the governing equations. This allows for a smooth transition between channel flow and Darcy's flow. Results show that erosion proceeds temporally at the high transport concentration front.

A model for investigating sandstone degradation and sand production mechanisms coupled with fluid flow analysis using the Discrete Element Method (DEM) is presented in [77]. The effects of in-situ stresses and flow rate on sand production were investigated using the model. A coupled DEM-fluid flow model for sand analysis was developed by the authors. The model computes percolation forces and transmits these to the solid particles in the DEM. Changes in permeability and porosity due to sandstone deformation and sand production are considered in the model. Pore elastoplastic analytical solutions were used to verify the DEM model. The model was then used to simulate the grinding of a block sample under different distant field stress and pressure conditions. In order to study their influence on sandstone degradation and sand production, the boundary stresses and fluid pressures were varied. The results obtained show that drilling a hole in a solid block resulted in the development of uniform or V-shaped fractures around the hole. After the application of fluid flow and sand grain detachment, the fracture zone around the hole expanded. The size and mode of failure in the fracture zone and sand production were observed to be influenced by fluid flow. Under higher boundary stress conditions, the boundary stress dominated the sanding response. Much less abrasion occurred under higher interfacial stress but low interfacial fluid pressure. Strong frictional interlocking, which mitigated sand production, resulted from high tangential stresses around the wellbore caused by high boundary stresses. At lower far-field stresses but higher pore pressure, massive sanding was observed.

[78] develops numerical models for the simulation of fluid flow conditions around the borehole and for the evaluation of the mechanisms pressure differences, governing fluid flow, rock failure, and the resulting sand production. According to the Drucker-Prager material failure model, the material behavior of the rock corresponds to sandstone. Erosion constraints are controlled by two criteria: a material failure criterion using the Drucker and Prager model, and a sand production criterion using a model for the generation of erosion solids. The interaction between the control of the operating conditions and the reservoir conditions will be evaluated. Furthermore, the contributions of the following key factors to interstitial fluid velocity, plastic deformation, pore pressure variation and sand production will be evaluated: decline, well perforation depth, mud pressure and erosion criterion. Sand production increases with wellbore/perforation depth despite a decrease in pore fluid velocity near the wellbore with increasing depth. Similarly, at constant drawdown, sand production is exacerbated with increasing wellbore depth. Plastic zone growth rate after sand production starts is not constant. In addition, mud pressure is shown to be an effective means of mitigating the production of sand. In order to optimize production operations, it is imperative to understand the interactions between key reservoir response parameters and their effect on sanding during oil/gas production.

A numerical model capable of characterizing the process of sand formation in gas hydrate-bearing sediments coupled with thermo-hydro-mechanical (THM) processes is presented in [79]. The numerical simulator is designed by introducing the newly developed particle migration module into the existing framework of the HydrateBiot coupled THMs simulator. A numerical study has been carried out to investigate the effect of various parameters on the extraction of sand, gas and water. The simulation results show that the sand production can be mitigated to some extent by reducing the pressure release rate without significantly affecting the gas production, while the particle detachment and migration mainly occur in the vicinity of the wellbore. Sand control equipment can effectively prevent sand production, however, clogging causes a substantial reduction in gas productivity. Sensitivity analyses of critical fluidization speed and solid/liquid speed show that an increase in solid particle concentration substantially affects water fluidity and gas productivity. It is also found that the massive particle detachment and migration can cause the appearance of clogging area in the vicinity of the wellbore and severely restrict the sustainable gas production.

An overview of methods for predicting sand production from experimental, numerical and field data can be found at [80]. The primary objective of this study is to identify the deficiencies of these methods. Experimental hollow cylinder test data and a well-established numerical simulation were used to investigate these shortcomings. The study uses two constitutive models (Mohr-Coulomb cohesion-softening/friction-hardening failure criteria and Mohr-Coulomb elastic-perfect plastic) and different element sizes and shapes are used to investigate the most important and fundamental parameters in numerical modelling. The choice of a finite difference program was due to the fact that most of the studies are continuum approaches. Furthermore, the fracture energy regularization method was applied to reduce the mesh dependency with respect to energy dissipation in order to reduce the undesirable influence factors. To show the effect of mesh size, shape and pattern on the results, a mesh size sensitivity analysis was also performed and cumulative probability distribution vs. absolute relative error plots were used to compare model accuracy. Finally, to simulate real sand production in a 50° incline, 6 SPF oil well in the North Sea reservoir, the best predictive model was selected.

Conclusion

1. The review highlights the application of the new technologies of sand consolidation (chemical consolidation - resin, polymer gels, foams etc., electromagnetic, microbial and nanoparticle consolidation) as an effective method for controlling sand production. Chemical sand consolidation agents offer advantages such as applicability in multi-completion wells, different perforation sizes, and open-hole completions. However, each agent has its own pros and cons, and the selection should consider cost, requirements, and reservoir conditions. Recent advancements in chemical sand consolidation, particularly the use of nanoparticles, have shown promising results in enhancing compressive strength without significantly reducing permeability and porosity. The ongoing improvement and innovation in sand consolidation materials and techniques offer potential for more efficient and effective sand control in unconsolidated formations.
2. The Halliburton SandTrap ABC, the Champion SC2020 and the Lubrizol SandAid systems involve injecting a specially formulated resin into the formation to consolidate the sand grains and create a strong, stable, permeable mass and it is typically used in unconsolidated or poorly consolidated sandstone formations where sand production is a major issue. Baker Hughes Sand Stop Aqua system consists of a blend of water, polymers, and other additives that form a gel-like substance when mixed. This gel is injected into the wellbore to form a filter cake, which helps to stabilize the formation and prevent sand particles from entering the wellbore. This solution has been designed to be effective in a wide range of reservoir conditions, including high-temperature, high-pressure, and high-salinity environments.

3. The article emphasizes the importance of a multidisciplinary approach to sand management, considering aspects such as sand prediction, monitoring, transport modeling, erosion control, and treatment. Sand management strategies should be tailored to the specific reservoir and well conditions, production life, and intervention costs to achieve sustained well productivity. It is crucial to evaluate the long-term costs and benefits of different sand control techniques, considering factors such as installation integrity, production rates, and remedial operations.
4. The effective sand control is essential for maximizing well productivity and preventing equipment damage in sand-prone reservoirs. Ongoing research and development in sand control techniques, prediction models, and monitoring technologies are crucial to improving the reliability and effectiveness of sand management strategies. By considering the unique characteristics of each reservoir and employing the most suitable sand control methods, the industry can mitigate sand production challenges and ensure the long-term success of oil and gas operations in unconsolidated formations.

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