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A Short Review of Sand Production Control

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Abstract

A large volume of hydrocarbon is produced during the formation of highly porous, permeable and well-cemented sandstone that can flow easily through sand and through perforations made in production wells. Hence, sand grain will lose their cohesion and friction forces that hold them together; this is how sand is produced. The sand will flow together with the hydrocarbon in the fluid stream through perforated production tubing. This poses many threats towards downhole equipment and topside facilities. Apart from this, the sand production also reduces the productivity of the wellbore. When sand is produced, it is a wise move to include sand control equipment in the completion stage. There are many sand control methods which are available in the industry to counter this problem. This study entails a short review of the methods of sand control in controlling sand production.

1. Introduction

Approximately 60% of oil and gas reserves are stored in sand formation (Bjørlykke and Jahren, 2010) that is defined as having a grain size between 62 μm and 2 mm (Assallay et al., 1998). In terms of the reservoir, sandstone rock is characterized by its porosity and permeability, which highly depends on the degree of sand domination (Taylor et al., 2010; Bataee and Irawan, 2014). Permeability is also influenced by the packaging of the grain size, whereby a uniform grain size is preferred due to the higher permeability, as compared to poorly sorted sandstone. A sandstone is a rock which consists of sand the size of quartz, and its grains size are nearly equivalent to each other and composed of silica cement with minimal fragment particles (Berg, 1970). Approximately 70% of the world's oil and gas is found in poorly consolidated formation (Alireza Nouri *et al.*, 2003b; Alireza Nouri *et al.*, 2003a; Duy, 2020). These formations are relatively not old in geologic age and are insufficiently consolidated because of the incomplete cementation through the natural processes. Moreover, the rock grains are still poorly held together (Dees, 1993). During the production of oil and gas from the wellbore, small particles and sand grains from the sand reservoir could be dislodged from their formation, and flow together with the fluids

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into the wellbore, prior to traveling up to the surface. This process is called sand production and is defined as a migration of formation sand from unconsolidated sandstone reservoir into the wellbore. However, this is not always the case. Sand production is usually linked with a weak reservoir formation. Sand production may be inevitable in unconsolidated sandstone formation with permeability between 0.5 to 8 darcies (Jon carlson et al., 1992) In addition, reservoirs with low formation strength (<1000 psi) are most susceptible to sand production (Salama, 2000).

In the hydrocarbon industry, sand production is among the most severe problems that leads to loss of production, constant cleanout and damage of downhole equipment. It occurs when the strength of the rock is lower than the stress around the wellbore (Dong et al., 2013). Hence, grains of the rock will lose their cohesion and friction forces that hold them together and start producing sand. The sand will flow together with hydrocarbon in the fluid stream through perforated production tubing (Sæther, 2010). This problem will occur during the first flow of hydrocarbon, or after few months of production, due to the drop in pressure (Jon carlson et al., 1992). There are three main factors that lead to sand production, namely, formation strength, the in-situ stress exerted on the wellbore after perforation and production rate. However, there is also potential for sand production in the consolidated reservoir during the life of the well due to the drastic changes in production rate in the well and water breakthrough (Morita et al., 1989; Skjaerstein et al., 1997). Many factors affect the rate of sand production, including “compressive strength”, which is the degree of consolidation, a mechanical characteristic of the rock (Chu and Yan, 2005). The compressive strength defines the strength of binding between the individual sand grains (Lorenzo and Bergado, 2003). The second geological process for consolidation is cementation (Franks and Forester, 1984). Sand producing zones are characterized by a small degree of cementation (Morita and Boyd, 1991). If the effective in-situ stress exceeds the formation strength, a sand formation that consists of a small degree cementation will produce sand, regardless of the degree of consolidation (Morita et al., 1989). Generally, poorly consolidated sandstone formations shows a compressive strength of less than 1,000 pounds per square inch (Kuncoro et al., 2001). During oil and gas abstraction from this sandstone, the most common issue is sand production. This normally occurs during the initial production, or from the second cycle of fluid production after the initial shut-in (Morita and Boyd, 1991).

Another reason for sand production is the rate of reservoir production fluids, which produce frictional drag forces and pressure differential, a combination of which may exceed the formation compressive strength. This illustrates the existence of sand production formed by critical flow rate, due to the differential pressure and frictional drag forces that are not great enough to exceed the formation compressive strength. The critical flow rate of a well is characterized by the highest production rate before sand production occurs. To minimize the production of sand, a method that keeps the flow rate down to the critical flow rate where there is no occurrence of sand production is used.

Other factors that contribute to sand production from the reservoir are reduction of pore pressure, viscosity of reservoir fluid, drawdown, and increasing water production.

The complexity of sand production prone formations is due to the different types of sand problems in the hydrocarbon field. Moreover, sand may be trapped in the production pipeline, or in the surface equipment like a separator. This may occur when the production velocity is great enough to carry sand up to the tubing (Tippie and Kohlhaas, 1973), which can cause extreme erosion and damage of both the surface equipment and downhole at high velocity (King *et al.*, 2003; Andrews *et al.*, 2005).

During fluid production, a considerable volume of sand may be produced. In addition, an empty area or void will form behind the casing as a result of the great rate of sand production. If this persists, it may develop wormhole-like structures, or giant cavities, in the formation (Andrews *et al.*, 2005; Kooijman *et al.*, 1996). This empty area may result in damage and casing collapse (Wan and Wang, 2004; Bataee *et al.*, 2016). On the other hand, when the production velocity is insufficient to carry sand out to the surface, sand may fall inside the casing and fill it, or bridge off in the tubing. To anticipate sand production rate, certain methods are used, namely, field observations, theoretical models (correlations) and laboratory experiments. Illustration from the performance of nearby offset wells in the field is the simplest way to predict sand production. To evaluate the stability of the formation, a sand flow test is used in exploratory wells. This test involves a drill stem test (DST) to detect and measure sand production on the surface (Hunter *et al.*, 2011). By gradually increasing the flow rate, quantitative information of sand producing may be obtained. Laboratory experiments on the core can be applied to measure the strength of a rock (Tronvoll and Fjaer, 1994). Theoretical models are developed and used to find a correlation between well data, field and sand production (Tronvoll *et al.*, 2001). Furthermore, detailed information about the mechanical strength of formation in terms of earth stresses and rock strain are required to predict the sand production potential.

2. Sand control technique

There are several sand control techniques that had been introduced to counter the problems. They are classified as mechanical and chemical one (Dees, 1992). Mechanical methods of sand control include using liners, screens or gravel packs to barricade sand production by stopping the formation. Chemical control methods include injection of resin as a consolidating material into the formation (Mathis, 2003; Xu *et al.*, 2008). There are some sand control techniques available in the market, including resin coated gravel, stand-alone slotted liners or screens, maintenance and workover, high energy resin placement, gravel packing, selective completion practices, plastic consolidation and rate exclusion.

2.1. Maintenance and workover

This method is a conventional method of controlling sand in the oil and gas industry. The method basically involves maintenance of the facilities to cope with the sand production. It requires routine cleaning and washing of the facilities to keep them productive. It is typically used in specific formations and operating fields. If the rate of production is low and involves a small volume of sand, the maintenance and workover method is effective, specifically in marginal wells where other techniques cannot be used (Speight, 2016).

2.2. Rate restriction

Restricting flow rate in the well to a specific level that decreases sand production is a method that is utilized sporadically. The procedure involves a consecutive increase or decrease of the flow rate until an acceptable rate of sand production is obtained (Tronvoll *et al.*, 2001). The maximum acceptable sand rate (MASR) is the main objective of this method (Andrews *et al.*, 2005). The reservoir pressure and the flow rate are changed through trial-and-error method. This method has a prominent limitations: the maximum flow rate that is always acceptable for sand production is generally less than the flow potential of the well (Speight, 2016).

2.3. Plastic consolidation

The plastic treatment method is used to bind sand grains in the formation by injecting plastic resins. These treatments are applied to immobilize the loose sand grains in order to form a strong matrix of artificial filler material. The treatments have been in use for many years, and the resulting surrounding wellbore area remains permeable to oil and gas (Rike, 1966). The use of resin as a consolidated material has been practiced since the 1940s, and was most commonly used between the 1960s and 1970s (Parlar *et al.*, 1998). The injected resin was reported to form a stable matrix of consolidated grains by the attachment of weak formations and interconnect loose grains at their contact points (Jon carlson *et al.*, 1992). The results show that formation compressive strength is increased (Parlar *et al.*, 1998). There are several types of resin which can be used in the consolidation of sand in the reservoir including epoxy resins, polyester resins, phenol–formaldehyde resins, urea–formaldehyde resins, furan resins, urethane resins and mixtures of such resins (Weaver and Murphey, 1990). The liquid form of resin has the advantage of easy entry into the formation. For hardening of the resin in the formation, a catalyst or curing agent is required for polymerization. Some catalysts are mixed with the resin at the surface, and need certain temperature levels and time to harden. This is called an "internal" curing agent. Meanwhile, some of them need to be injected after the resin is in place, and is called "external" curing agent (Spain, 1962). For example, the catalyst of furans and furan/phenolic blends needs to be injected externally due to the rapid curing time of these materials. Epoxy and phenolic based resins can be placed with both internal and external catalysts (Speight, 2016). Different companies will use different consolidation processes, such as Esso and Dow, which use Phenol–formaldehyde, Shell and Chevron that use epoxy, Halliburton that use Furan; while Continental Oil uses Furan–phenolic for the consolidation process (Talaghat *et al.*, 2009). Although the application of resin injection is proven to be efficient in handling sand production, the fact that it can reduce the permeability of the formation should not be neglected. Therefore, the amount of resin injected must be optimized to compromise between increasing formation strength and reducing permeability (Jon carlson *et al.*, 1992). Chemical treatment has some disadvantages such as high cost and difficultly to obtain uniform injection of resin across the entire formation. In widely varying permeability formations such as lenticular formations, the chemical injection may be uneven, and some parts are likely to be untreated and make intervals that may break down during the production, hence the sand may be washed out. Resin consolidation is appropriate for intervals that are less than 10 to 15 ft in length (Dees, 1993). On the other hand, in low permeability (less than about 50 md) and high temperature (more than 255°F), plastic consolidation treatments do not accomplish well (Patil *et al.*, 2014).

2.4. Resin-coated gravel

Resin-coated gravel treatments are gravel pack sand coated with a thin layer of a fusible thermosetting resin (Graham *et al.*, 1982). The method of treatment in the subterranean environment is according to US Pat. No. 3,929,191. According to this patent, particles are coated by resin. The resin that is required has a composition of about 5% of the total weight of the sand. James Speight in the Handbook of Hydraulic Fracturing mentioned that there are two ways to perform resin coated gravel sand pack (Speight, 2016). The dry way is the perforations and casing in the formation that are completely filled by pumping the gravel into the well. When the resin coated gravel is exposed to heat coming from the bottom hole temperature of the well, or through injection of steam, the curing process in the condition of infusible solid into a consolidated pack by coating and hardness contiguous particles to fuse together. The gravel-packed sand can be drilled out of the casing after curing, and the resin-coated gravel will remain in the perforations. This consolidated gravel works as a permeable filter to prevent the production sand from the process of formation. Wet resins (epoxies or furans) can also be used to cure the perforation and open holes, where the well filled with gravels is then injected with resin and catalyzed to harden, and spread across the production zone, where it is then squeezed to form a plug. After curing and drilling the consolidated plastic-sand mixture out, the resin-coated sand is left in the perforations. Both methods produce a strong, consolidated and permeable framework for conduction of formation fluids (Speight, 2016). This method has some limitations, including difficulty in controlling curing temperature in the formation. Reservoirs with low temperature are not able to complete the curing process. Some resins require temperatures below 130° F to cure, while some cure slowly at temperatures below 200° F (Graham *et al.*, 1982).

2.5. Sand Screen

The sand screen is a filtration equipment consisting of sophisticated screened pipe joints which are installed inside the wellbore that filters sand during the production of hydrocarbon from the well. It is an important sand control because this is the final barrier to prohibit sand from getting into the wellbore (Yeh *et al.*, 2010). Manufacturing of sand control devices must follow the ISO Sand Control Screen Standard (ISO 17842), where the sand control screens must have the ability to act as a filtration device that provides sand retention of the gravel pack and formation sand, without restricting the hydrocarbon flow into the wellbore (Ott, 2008). This is to assure long-term well reliability and productivity. Any damage in the sand screen may allow sand to flow with the fluid and impact the productivity of the well.

2.5.1. Type of sand screen

The purpose of implementing sand screen is to protect the wellbore from entering sand, and to protect the surface or downhole facilities from any damage caused by the sand (Robisson *et al.*, 2014). In open hole completion, the sand control method can be divided to two types: compliant and non-compliant sand screens (Aborisade, 2011).

i. **Compliant sand screen**; the compliant sand screen is a sand screen that supports the wellbore without an annulus (Aborisade, 2011). It is composed of a metallic mesh material and placed in between annulus and formation (Robisson *et al.*, 2014). The compliant screen can resist high external pressure. An example of compliant sand control is an expandable sand screen, which, however, may not be able to resist high external pressure due to plastic deformation of the metallic components (Robisson *et al.*, 2014). The compliant screen can provide long-term productivity and reliability in the long run (Aborisade, 2011). Based on US patent no US8783349 B2 (Robisson *et al.*, 2014), the self-expandable polymer screen has greater expansion ratio. Even though the shape of the borehole is irregular, this screen can always be in contact with the entire length of borehole. However, self-expandable polymer screen has a foam with weak mechanical properties that can cause the screen to collapse under wellbore pressure. As a result, it will lead to it being stuck in the completion string and can thus lose its permeability. The compliant sand screen will remove the annulus, which will affect the integrity of the completion through yielding. Higher skin will be formed from the yielded rock due to its low permeability. Thus, the screen will collapse when large loads are applied to it, which will thus reduce the production and block the fluid access into the well (Bybee, 2004).

ii. **Non-compliant screen**; the Non-compliant screen is a sand screen that does not support the wellbore due to the presence of annular space in between the screen and the formation. It provides excellent sand control, greater productivity and is a reliable sand control technique. This type of screen is less complicated, and is not capable to overcome challenging situations. There are two types of non-compliant sand screens, which are stand-alone and non-compliant expandable screens (Aborisade, 2011). According to Tovar et al. (Tovar *et al.*, 2011), if the external diameter of the completion does not reach the wellbore wall, it means the well uses a non-complaint screen. Nowadays, there are many types of non-compliant sand screen which are widely use in the oil and gas industry, including slotted liners, wire-wrapped screens, pre-packed screens and metal mesh screens.

iii. **Slotted Liner**; Slotted liner is made up of tubing with slot configurations usually installed with gravel pack between the liner and casing or open hole. There are two types of slots designed for the slotted liner, namely, straight slot and keystone slot. The keystone slot has an inverted "V" cross-sectional area. The opening of the slot is designed to be narrower on the outside of the pipe. This characteristic could prevent the keystone slotted liner from clogging. In the oil and gas industry, slotted liners have been used for many years, such as in Western Canada oil sands fields, where it was applied in highly unconsolidated reservoirs. It was found that the straight-cut slotted liners with short slot lengths perform well under installation and operational loads. This new design is comparable with the traditional saw-cut slotted liner designs (Xie, 2015).

iv. **Wire-wrapped Screen**; Wire-wrapped screen (WWS) is another alternative mechanical device for sand control. It was invented in the 1970s, and consists of three major parts; wire wrapped screen, base pipe and boss rings (Van Vliet and Hughes, 2015). Although WWS is cheap with good conformation at the lower part, and offers more inflow area when compared to the slotted liner, it could cause plugging of the formation sand with inaccurate wire spacing. Duri Steam Flood (DSF) field in central Sumatra basin, Indonesia, has been reported to have clogs of wire wrap screens in their wells. Different approaches were applied to overcome this problem, including jetting with acid using coiled tubing and bull heading acid diverted with benzonic acid flakes. The result show a good response of removing plugged material without disturbing the gravel pack (Wijaya and Portman, 2003). Apart from this, WWS is not suitable and is subject to damage when installed through doglegs and horizontal wells (Ott, 2008).

v. **Pre-packed Screen**; This is a modification of WWS which is utilized with resin-coated gravel to fill the annular space across the screen and casing, or open hole controlled by an outer shroud (single-screen per pack) or second screen (dual-screen per pack). The pre-packed screens are moderate in cost, can withstand some erosion, the easiest to plug, and are a suitable choice for the upper part of a horizontal well and in vertical wells, but are easily damaged in running operations. Chemically impregnated substrates were used to solve sand production in the well as pre-packed screen. The result indicate that appropriate sizing of the substrate, using gravel pack proppant and applying a particular, and enlarged pre-packed screen can produce impressive results of chemical treatments in various well completions (Weirich *et al.*, 2011).

vi. **Metal Mesh Screen**; Metal mesh screen is commonly used as a standalone screen for unconsolidated formations to control sand production. This screen alludes as a premium screen (Mondal *et al.*, 2016). There are two types of metal mesh screens. The first is layered with non-uniform pores, and was invented in the 1980s. It consists of base pipe, uneven layered pore filtration jacket and the outer shroud, and is less prone to damage during installation. The second one is sintered laminate with uniform pores, which was introduced in the 1990s. It consists of a base pipe, uniform multi-layer sintered jacket and the outer shroud, and is less also prone to damage during installation (Matanovic *et al.*, 2012). The Ostra field in Campos Basin (block BC-10), Vitoria, Brazil which is operated by Shell, is known to have sand production problems. A series of laboratory tests were performed to evaluate the implementation of stand-alone woven mesh screens and gravel packs. The study was carried out to reduce the sand production by choosing an appropriate mesh screen in addition to gravel pack (Martch *et al.*, 2012).

Prepacked screens, wire-wrapped screens and slotted pipes were found to be suitable filters for high-angle wells. They are relatively low in cost for downhole filtering. The notable characteristic of slotted liners is the set of large holes, while that of wire-wrapped screens is its small openings. However, the finest filtering is provided by screens prepacked with resin-coated sand. Each type has its own advantages, and can be used as a part of the completion string. Slots are generally connected to more than 10% of particles within the formation, and fill the open hole or annulus between casing and screen, with the formation sand building a filter for the remaining grain and particles. This may cause low permeability in the sand packed, which affects production. During installation, the production of a small amount of fine grain, even for a few hours, can cause the plugging of the screen, especially prepacked screens. However, screens and slotted liners are more suitable in friable formation compared to the unconsolidated formation.

2.6. Ceramic sand screens

The erosion of downstream equipment is a severe operational issue in oil and gas production. Sand screens generally consist of metals that have limited persistence to erosion. The material properties are the main factor that determines the degree of resistance against erosion. Researchers have tried to find sand screens that can remain undamaged or unaffected by abrasion and erosion. In 2010, a ceramic sand screen was found to be 50 times harder than steel, and show no attrition and corrosion under various reservoir conditions. This material could resists various acids and bases, even at a higher temperature (Jackson *et al.*, 2016). Properties such as high hardness, low density, excellent corrosion resistance, and high firmness make ceramic a unique material (Muessig *et al.*, 2011) in sand control under high erosive environments. A good example of using ceramic sand screen is in Tunu Field, East Kalimantan, Indonesia, where shallow gas development in this field requires a cost-effective solution to secure production from multi-layered sand prone reservoir. Traditionally, since 2006, a gravel pack solution was applied to prevent sand production from lower reservoir layers, but the system reaches its technical limits in term of cost, a number of completed zones and well deviation. The ceramic sand screen was applied to overcome these limitations. This method shows good performance in terms of a number of fines produced during clean-up operations, and achieved satisfactory productivity (Risatrio *et al.*, 2015). However, ceramic screen has the disadvantage of being brittle. To overcome this problem, ceramics are formed in-situ on a metal base, which conventional metallic screens such as boronising, inchromising, aluminizing, titanium and cobalt alloys, Kevlar, carillon, metal composites and fiber/polymer composites can be used (Arukhe *et al.*, 2005).

2.7. Inflow Control Devices

In the early 1990s, Inflow Control Devices (ICDs) were used to control plugging of screens, severe erosion "hot-spots" and annular flow. A variety of field monitoring techniques were applied to control the good inflow profile. ICD is a part of the sand face completion hardware, and is used as a choking device. It can reduce the annular flow in terms of a limited, extra pressure drop, and is also used to equilibrate the horizontal well's inflow profile (Al-Khelaiwi and Davies, 2007). The efficiency of ICD has been demonstrated in many kinds of reservoir environments for optimizing the optinal influx profile, and increasing the optimal life standards by reducing water and gas coning. In the offshore of Gabon, Etame oil field (Subsea ET-6H well), ICDs and gravel pack combination were used to mitigate sand problems, and to delay water breakthrough (Bybee, 2008). Another example is in the Norsk Hydro Troll Field, where the application of ICD in long horizontal wells was successful in terms of delaying gas coning (Freyer *et al.*, 2002; Henriksen *et al.*, 2006).

2.8. Frac Packing

Frac Packing is a method of sand control which combines both chemical and mechanical techniques. It involves the injection of high viscous fluid into the wellbore at a pressure above the fracturing pressure to crack open the formation (Sanchez and Tibbles, 2007). Generally, most of the frac-pack methods are performed in cased holes. Simultaneously, a slurry containing gravel is injected to fill the opening of the fracture at the formation. The most significant advantage of frac packing is that it has a long lifespan, and allows a high flow rate during production. The disadvantage of frac packing are made apparent when it is exposed to high transmissivity environments. This limitation is obvious in high-performance wells, where perforations are the dominant restriction to flow (Welling and Wong, 1998). A case history of an open hole frac pack application technique is in the Widuri field offshore of Java Sea, Indonesia. The technique saved a well that was almost lost (Saldungaray *et al.*, 2002).

2.9. Gravel packing

Gravel pack is the most common sand control that is applied in the oil and gas industry. It has a high rate of success (up to 70%) (Saucier, 1974). Just like resin injection, a slurry containing gravel is pumped into the annular space, forming a filter made of granules with a very high permeability of about 120 darcies (Jon carlson *et al.*, 1992). It is probable that this method is the most widely-used technique in controlling the production of sand from a formation. A gravel pack is formed in the well adjacent to the part where unconsolidated or poorly consolidated formation is exposed to the well. The gravel is sized so that it forms a permeable mass which allows the flow of the produced hydrocarbons. While gravel packing can effectively control the sand production, it reduces well productivity, increases well cost and necessitates workovers (Chambers and Sprunt, 1995).

Studies reveal that the gravel pack treatment is the optimal method for sand control in cases of high flow capacity reservoirs where maximum performance is desired (Zaleski Jr, 1991; Fahel and Brienen, 1992). The gravel pack treatment shows the best performance in terms of sand control technique. However, this treatment is the most expensive (Zaleski Jr, 1991). Gravel pack treatment involves filling the annular space between the centralized slotted liner or the wire-wrapped screen and unconsolidated sediments by placing a granular filter. Generally, gravel packing is applied in the cased hole which has high productivity. Moreover, gravel pack treatments are also used in open hole and under-reamed completions.

Gravel packing works as a permeable filter which prevents the production and entry of sand, but allows the production of the formation fluids. The disadvantages of gravel packing are higher cost, low inflow area, vulnerability to erosion, low reliability, and the ability to be easily clogged. Gravel packs are generally not used for heavy oil or bitumen reservoirs, though they are used extensively around the world for conventional/light oil from clastic unconsolidated reservoirs that require high inflow rates. In Vienna basin, Austria, sand production problems from unconsolidated sand formations in a domestic oil well of OMV could be overcome by gravel packing. The performance of the well in terms of production shows that gravel pack could be successfully installed in slim holes (Gollob, 1992). The researcher found that the use of the gravel packing for Albacora and Marlim in the offshore fields in northeast Brazil is unique and is among the challenges in deepwater production. The gravel packing technique was found to be the only suitable technique of sand control in the areas (De Sa *et al.*, 1989).

3. Conclusion

This paper presented an in-depth review of sand production, and the reason for the production and its control. Various methods are available for the control of sand production, and these methods can be applied individually, or in a combination. These methods range from simple changes in the operating system, to expensive completions. Based on good completion, the optimal technique should be selected. In production wells, sand inflow into the well may cause damage and erosion to equipment, and reduction in productivity and in turn the loss of the well. The inflow of sand may cause production problems that contribute to the additional cost. These include erosion damage to downhole tubular equipment and valves; downhole casing and formation damage that may lead to a premature crack at completions; bridging of sand inside the wellbore that clog production; sand accumulation in equipment and surface lines; and abrasive wear on the surface, valves, and pipes. Moreover, in offshore and inland water location, unexpected pipe leaks or equipment failure may cause a spill of hazardous substances, as well as serious safety implications. All these problems may be eliminated by sand control techniques. The selection of the optimal sand control method highly depends on the site-specific conditions, operating practices and economic considerations.

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