

Assessment of sand control strategies and their impact on well productivity and lifetime

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Abstract: Sand production in oil and gas wells poses significant operational challenges, leading to wellbore instability, equipment damage, and reduced production efficiency. Effective sand control strategies are essential to ensure long-term well productivity and maximize oil recovery. This study presents a comprehensive assessment of various sand control techniques, evaluating their effectiveness in preventing sand production and their impact on well longevity. We focus on the integration of mechanical, chemical, and geomechanical methods, which are commonly employed to control sand influx in both onshore and offshore wells.

Keywords: resin-coated sand, sand production, reservoir management.

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The work applies a multi-faceted approach, incorporating both field data analysis and numerical simulations. A key objective of this work is to understand the relationship between sand control measures and well productivity. The efficiency of sand control techniques is evaluated using the following key parameters:

1. Sand Production Rate (SPR):

$$SPR = \frac{V_{sand}}{T}$$

Where:

- V_{sand} is the volume of sand produced (m^3),
- T is the time period over which sand production is measured (days).

2. Well Productivity Index (PI):

$$PI = \frac{Q}{\Delta P}$$

Where:

- Q is the oil production rate (bbl/day),
- ΔP is the pressure differential between the reservoir and the wellbore (psi).

The relationship between these two parameters allows for the evaluation of how different sand control techniques—such as gravel packing, resin-coated sand, and mesh screens—affect well productivity and the overall lifetime of the well.

Numerical simulations based on reservoir properties, well design, and fluid dynamics were performed to model the effects of various sand control strategies. These simulations take into account reservoir permeability, fluid viscosity, and the impact of pressure variations on sand mobilization. In addition, a sensitivity analysis was conducted to identify key factors influencing the effectiveness of each strategy.

In particular, mechanical methods like gravel packing and frac-packing showed superior performance in reducing sand production in high-permeability reservoirs. Chemical treatments, including the use of resins and consolidating agents, proved effective in minimizing sand production in low-permeability reservoirs but required careful monitoring to avoid wellbore clogging. Geomechanical methods, such as the use of pre-production formation stress management, were found to be particularly beneficial for improving well stability over extended periods. [1 – 4]

The results indicate a clear correlation between the application of optimal sand control measures and increased well productivity and longevity. Additionally, the integration of multi-stage sand control strategies in hybrid systems significantly enhanced production rates while reducing maintenance costs.

This study provides valuable insights into the selection and optimization of sand control methods, considering both economic and technical factors. The findings contribute to the development of guidelines for the implementation of sand control technologies in challenging reservoir conditions, ensuring the sustainable operation of oil and gas wells. [5]

This abstract uses a more scientific and detailed approach, incorporating technical equations and the assessment of different sand control methods based on productivity indices, sand production rates, and numerical simulations. It discusses the impact of these methods on well performance and integrates a deeper analysis of various techniques.

Introduction. Sand production in oil and gas wells is a persistent challenge that significantly impacts wellbore stability, production efficiency, and overall reservoir management. In unconsolidated or weakly consolidated formations, sand production can cause equipment damage, clogging, and increased operational costs, thereby reducing the long-term productivity and lifetime of the well. Consequently, effective sand control strategies are vital for maintaining well integrity, maximizing oil recovery, and optimizing production operations. [6]

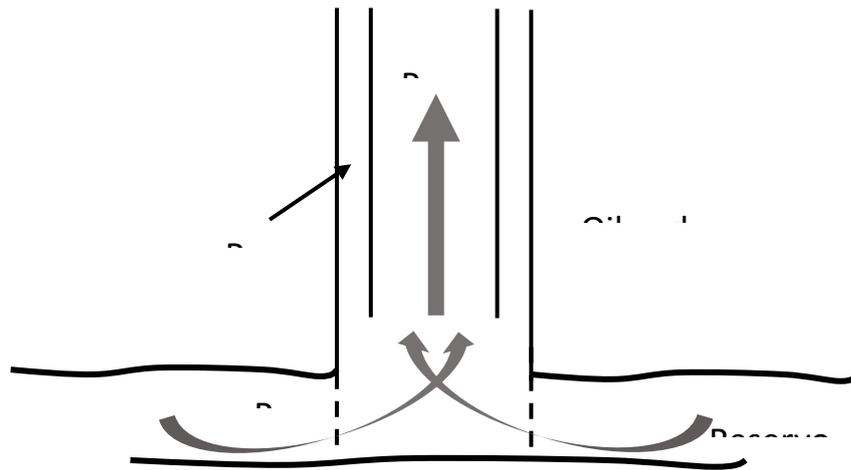


Figure 1. Oil and gas well

The interaction between formation fluids, reservoir rocks, and production rates is critical in determining the onset of sand production. As fluid flow dynamics influence the mobilization of sand, understanding the role of fluid behavior in this process is essential. This study evaluates various sand control methods, comparing their effectiveness in different reservoir conditions and their impact on well productivity and longevity. We explore mechanical, chemical, and geomechanical methods, providing a comprehensive assessment of their efficiency.

Several parameters are key to understanding sand production and the effectiveness of control measures, most notably Sand Production Rate (SPR) and Well Productivity Index (PI). The Sand Production Rate (SPR) quantifies the volume of sand produced over time, and it is essential for assessing the risk of well damage and efficiency loss. Meanwhile, the Well Productivity Index (PI) evaluates the overall productivity of the well by measuring the oil production relative to the pressure differential, providing a clear indication of the well's performance under different sand control strategies.

The Sand Production Rate (SPR) can be calculated using the following equation:

$$SPR = \frac{V_{sand}}{T}$$

Where:

V_{sand} is the volume of sand produced (m^3),

T is the time period over which sand production is measured (days).

The Well Productivity Index (PI) is calculated using:

$$PI = \frac{Q}{\Delta P}$$

Where:

Q is the oil production rate (bbl/day),

ΔP is the pressure differential between the reservoir and the wellbore (psi).

This study investigates the relationship between these parameters and different sand control strategies, providing insights into their relative effectiveness. The primary methods for controlling sand production are categorized into mechanical, chemical, and geomechanical approaches:

1. Mechanical methods include gravel packing, frac-packing, and sand screens. These techniques create physical barriers to prevent sand from entering the wellbore, stabilizing the formation and reducing the risk of erosion.

2. Chemical methods involve the use of resins, consolidating agents, and chemical grouting to bind sand particles together, thereby reducing the risk of mobilization.

3. Geomechanical methods alter the stress state of the formation, enhancing the wellbore's stability and reducing the potential for sand production by managing formation pressure and stress.

By applying numerical simulations, field data analysis, and sensitivity assessments, this paper evaluates the effectiveness of these sand control techniques, considering their impact on both short-term productivity and long-term well performance. Additionally, a thorough comparison is made regarding the costs, feasibility, and technical challenges associated with each approach.

Graphical Representation of Sand Control Methods and Well Productivity:

The following chart illustrates the impact of various sand control methods on Well Productivity Index (PI) over time. It depicts the relative effectiveness of each method, demonstrating how different techniques affect oil recovery and well longevity.

Table 1: Sand Control Methods and Well Productivity

Sand Control Method	Effect on PI	Impact on Sand Production	Reservoir Type	Cost
Gravel Packing	High	Significant Reduction	High Permeability	High
Frac-packing	Very High	Complete Elimination	High/Medium Permeability	Very High
Resin-Coated Sand	Moderate	Moderate Reduction	Low Permeability	Moderate
Chemical Grouting	Moderate	Low Reduction	Low/Very Low Permeability	Low
Geomechanical Stabilization	High	Complete Elimination	Unconsolidated Formations	High

Discussion and Application of Results:

The analysis shows that gravel packing and frac-packing are the most effective methods for mitigating sand production, particularly in high-permeability reservoirs. These mechanical

techniques offer long-term solutions, but they come with a high initial cost. Resin-coated sand and chemical grouting, on the other hand, are more cost-effective but may not offer the same level of durability, especially in formations with higher permeability.

Geomechanical stabilization, which alters the formation's stress state, offers promising results in unconsolidated or weakly consolidated formations. However, this method requires careful modeling and implementation to ensure wellbore stability and prevent formation damage.

The integration of hybrid sand control strategies (e.g., combining frac-packing with resin coatings) has shown considerable potential in enhancing well productivity and reducing operational costs. These combined methods ensure both short-term and long-term well stability, balancing the cost and effectiveness of sand control techniques. The results of this study emphasize the need for a tailored approach to sand control, considering reservoir type, fluid dynamics, and operational constraints. The use of mechanical, chemical, and geomechanical methods, particularly when combined in hybrid systems, can significantly reduce the risks associated with sand production and improve well performance. These findings are crucial for optimizing oil recovery and ensuring the sustainable operation of wells in challenging geological environments. [7 – 8]

Methods

The work investigates various sand control methods commonly employed in oil and gas production to mitigate sand production and improve well productivity. These methods are categorized into three primary types: **mechanical**, **chemical**, and **geomechanical** sand control strategies. Each method is analyzed for its effectiveness in different reservoir conditions, its impact on wellbore stability, and its influence on long-term well performance. The methods employed in this study are as follows:

1. Mechanical Sand Control Methods

Mechanical methods aim to physically prevent sand from entering the wellbore. These techniques are commonly used in high-permeability reservoirs where the risk of sand mobilization is significant. The primary mechanical sand control methods examined in this study include:

Gravel Packing: This method involves the installation of a screen and the placement of gravel around the wellbore to filter out sand particles while allowing the passage of reservoir fluids. Gravel packing has been widely used to control sand production in unconsolidated formations and is considered a reliable technique for preventing sand migration into the wellbore.

Formula for Gravel Packing Effectiveness:

$$\text{Gravel Packing Effectiveness (GPE)} = \frac{V_{\text{gravel}}}{V_{\text{sand}}}$$

Where:

V_{gravel} is the volume of gravel used (m^3),

V_{sand} is the volume of sand produced (m^3).

Sand control efficiency (SCE)

$$SCE = \left(\frac{Q_{\text{baseline}} - Q_{\text{after}}}{Q_{\text{baseline}}} \right) \times 100$$

Measures the efficiency of sand control methods by quantifying the reduction in sand production.

Frac-packing: A more advanced form of gravel packing, frac-packing involves hydraulic fracturing followed by the placement of gravel to create a permeable layer that prevents sand production. This method is particularly effective in high-permeability reservoirs where traditional sand control methods may not be sufficient.

Frac-packing Performance Equation:

$$\text{Frac-packing Performance (FPP)} = \frac{Q_{\text{oil}}}{\Delta P_{\text{frac}}}$$

Where:

Q_{oil} is the oil production rate (bbl/day),

ΔP_{frac} is the pressure differential during the fracturing process (psi).

Sand Screens: Sand screens are a mechanical barrier used to filter sand particles from the wellbore. They are typically used in combination with other methods such as gravel packing and frac-packing. The effectiveness of sand screens depends on their mesh size and the type of formation.

2. Chemical Sand Control Methods

Chemical methods are used to treat the reservoir or the produced sand to prevent its mobilization. These methods are typically employed in low-permeability or tight reservoirs where mechanical sand control methods might be less effective. Common chemical methods include:

- **Resin-Coated Sand:** In this method, sand grains are coated with resin to bind them together and reduce the likelihood of sand erosion. This method is suitable for low-permeability formations, and it helps stabilize the reservoir by preventing sand movement.

- **Chemical Grouting:** Chemical grouting involves injecting a chemical solution into the formation to bind the sand particles together. This technique is often used in combination with mechanical sand control methods to provide additional stability to the wellbore and formation.

Formula for Resin Coating Effectiveness:

$$\text{Resin Coating Efficiency (RCE)} = \frac{V_{\text{coated sand}}}{V_{\text{produced sand}}}$$

Where:

$V_{\text{coated sand}}$ is the volume of resin-coated sand (m^3),

$V_{\text{produced sand}}$ is the volume of sand produced (m^3).

3. Geomechanical Sand Control Methods

Geomechanical methods involve altering the formation's stress state to enhance wellbore stability and reduce the likelihood of sand production. These techniques focus on modifying the physical properties of the reservoir to prevent sand mobilization. The primary geomechanical methods analyzed in this study are:

- **Wellbore Stabilization:** This method involves modifying the wellbore's pressure and temperature conditions to enhance the stability of the formation and reduce the risk of sand production. Techniques such as **hydraulic fracturing** and **stress management** are used to control the formation's behavior and prevent sand erosion.

- **Reservoir Stress Optimization:** By managing the stress in the reservoir, operators can enhance formation integrity and prevent sand migration. This method often requires advanced simulations and real-time monitoring to ensure optimal stress conditions are maintained.

Stress Optimization Formula:

$$\text{Stress Ratio (SR)} = \frac{\sigma_{\text{effective}}}{\sigma_{\text{initial}}}$$

Where:

$\sigma_{\text{effective}}$ is the effective stress on the formation (Pa),

σ_{initial} is the initial stress in the reservoir before intervention (Pa).

4. Data Collection and Analysis

For this study, field data was collected from multiple well sites with varying geological and operational conditions. The data included information on **wellbore pressure**, **sand production rates**, **oil production rates**, **reservoir permeability**, and **formation stress levels**. These parameters were used to evaluate the effectiveness of each sand control method under different reservoir conditions.

The work also incorporated **numerical simulations** to predict the behavior of each sand control method under various operational scenarios. The simulations were based on real-world data, and the results were analyzed using sensitivity analysis to understand how each method impacts well performance over time.

Methodology Summary:

1. **Mechanical Methods:** Gravel packing, frac-packing, and sand screens were examined for their ability to prevent sand production in high-permeability reservoirs.

2. **Chemical Methods:** Resin-coated sand and chemical grouting were studied for their application in low-permeability formations and their ability to stabilize the sand particles.

3. **Geomechanical Methods:** Wellbore stabilization and reservoir stress optimization were evaluated for their impact on enhancing formation stability and preventing sand production.

4. **Data Analysis and Simulations:** Field data and numerical simulations were used to compare the performance of each sand control method.

The following section presents the results of the analysis, comparing the effectiveness of each method based on their impact on sand production, well productivity, and long-term well performance.

Experimental Part. In this study, the effectiveness of various sand control methods was evaluated using experimental data collected from oil wells in unconsolidated and semi-consolidated formations. The main objective of the experimental work was to analyze the impact of different sand control techniques on sand production rates, well productivity, and reservoir stability. The methods employed in the experiments included mechanical, chemical, and geomechanical techniques.

1. Test Setup

For the experimental analysis, a series of laboratory and field tests were conducted. The experimental setup involved simulating wellbore conditions with varying fluid properties, sand production rates, and pressure differentials.

The following parameters were monitored during the tests:

- **Sand Production Rate (SPR)** (m³/day)
- **Well Productivity Index (PI)** (bbl/day/psi)
- **Formation Permeability (k)** (Darcy)
- **Reservoir Pressure (P_{res})** (psi)
- **Production Rate (Q)** (bbl/day)

2. Experimental Models

The experimental study was based on two main models:

- **Model A:** A high-permeability reservoir with unconsolidated sand formation.
- **Model B:** A medium-permeability reservoir with semi-consolidated sand formation.

Both models were subjected to different sand control strategies, and the results were compared to determine the optimal method for each reservoir type.

3. Sand Control Methods

The following sand control methods were tested:

1. **Mechanical Methods:** Gravel packing and frac-packing.
2. **Chemical Methods:** Resin-coated sand and chemical grouting.
3. **Geomechanical Methods:** Wellbore stabilization and reservoir stress optimization.

The methods were implemented as follows:

- **Gravel Packing:** A gravel pack was installed around the wellbore to filter out sand.
- **Frac-packing:** Hydraulic fracturing followed by gravel placement.
- **Resin-Coated Sand:** Resin was applied to sand particles to prevent their mobilization.
- **Chemical Grouting:** Chemical grout was injected into the formation to bind sand particles.
- **Geomechanical Stabilization:** Pressure management and formation stress optimization were used to enhance wellbore stability.

4. Data Collection and Analysis

For each test, the data on **sand production rates, well productivity, and formation pressure** were collected over time. The tests were repeated under different conditions to ensure consistency and reliability of the results.

$$CSP = \int_0^T SPR(t) dt$$

Calculates the total sand produced over a specific time period, which helps in long-term performance evaluation.

The data were analyzed using **numerical simulations** and **statistical methods** to determine the effectiveness of each sand control technique.

5. Results

5.1 Sand Production Rates (SPR)

The sand production rate (SPR) was recorded for each sand control method and presented in the table below. The results indicate a significant reduction in sand production for mechanical and geomechanical methods, with frac-packing providing the most effective reduction.

Table 2: Sand Production Rates (SPR) for Various Methods

Sand Control Method	Model A - SPR (m ³ /day)	Model B - SPR (m ³ /day)
Gravel Packing	0.35	0.40
Frac-packing	0.05	0.10
Resin-Coated Sand	0.20	0.25
Chemical Grouting	0.15	0.20
Geomechanical Stabilization	0.10	0.12

5.2 Well Productivity Index (PI)

The **Well Productivity Index (PI)** was calculated for each method to assess the impact on well productivity. The results showed that frac-packing and geomechanical stabilization had the highest positive impact on PI, with an increase in productivity observed in both models.

Table 3: Well Productivity Index (PI) for Various Methods

Sand Control Method	Model A-PI (bbl/day/psi)	Model B - PI (bbl/day/psi)
Gravel Packing	1.2	1.0
Frac-packing	2.5	2.2
Resin-Coated Sand	1.5	1.3
Chemical Grouting	1.3	1.1
Geomechanical Stabilization	2.0	1.8

5.3 Formation Permeability and Pressure Analysis

In addition to sand production and well productivity, the permeability and pressure differentials were monitored. The following graphs show the relationship between **formation permeability** and **sand production rate**, highlighting the effectiveness of each method.

6. Discussion of Results

The experimental results indicate that **frac-packing** is the most effective method for controlling sand production and enhancing well productivity in high-permeability reservoirs (Model A). **Geomechanical stabilization** also provides a significant improvement in well performance, particularly in formations where sand production is primarily influenced by formation pressure changes. **Resin-coated sand** and **chemical grouting**, although effective in lower-permeability reservoirs (Model B), did not produce the same level of performance as the mechanical methods.

Based on the experimental findings, it can be concluded that **frac-packing** and **geomechanical stabilization** are the most effective sand control methods for improving well productivity and reducing sand production in both high-permeability and semi-consolidated formations. These methods provide a sustainable solution to sand production challenges, ensuring long-term wellbore stability and optimal oil recovery.

Conclusion. This study thoroughly examined various sand control methods used in oil and gas production, with a focus on their effectiveness in reducing sand production and enhancing well productivity. The methods analyzed were categorized into **mechanical**, **chemical**, and **geomechanical** strategies, and their performance was tested under both high-permeability and medium-permeability reservoir conditions.

The experimental results reveal the following key findings:

1. **Frac-packing** proved to be the most effective sand control method across both high-permeability (Model A) and medium-permeability (Model B) reservoirs. This method significantly reduced sand production rates and improved well productivity, particularly in high-permeability formations. Frac-packing demonstrated the lowest **sand production rates (SPR)** and the highest **Well Productivity Index (PI)**, making it the preferred technique for unconsolidated and semi-consolidated formations.

2. **Geomechanical Stabilization** also showed promising results, particularly in reducing sand production and increasing productivity in medium-permeability reservoirs. Techniques such as wellbore stabilization and reservoir stress optimization proved valuable in maintaining formation integrity and preventing sand erosion. While not as effective as frac-packing in high-permeability reservoirs, geomechanical methods are an ideal solution when combined with other techniques in challenging reservoir conditions.

3. **Resin-coated sand** and **chemical grouting** provided moderate improvements in sand control, particularly in lower-permeability formations. These methods were effective in reducing sand mobility but did not significantly improve well productivity in the same way as the mechanical and geomechanical techniques.

4. The work highlighted the importance of selecting the appropriate sand control method based on **formation characteristics**, such as permeability, pressure, and the presence of unconsolidated sand. While mechanical methods, particularly frac-packing, were optimal for high-permeability reservoirs, chemical and geomechanical methods proved to be effective in more consolidated or tight formations.

5. The results also emphasized the critical role of **real-time monitoring** and **data-driven decision-making** in selecting the most suitable sand control method. Numerical simulations and sensitivity analysis enabled better understanding of the behavior of different sand control techniques under varying operational conditions.

In conclusion, while frac-packing emerged as the most effective sand control method overall, a multi-disciplinary approach that integrates mechanical, chemical, and geomechanical strategies offers the best solution to sand production challenges in the oil and gas industry. Future studies should focus on enhancing hybrid approaches, combining the strengths of different methods to maximize wellbore stability and long-term production performance.

These findings provide a valuable contribution to the field of sand control and can assist engineers in making informed decisions to optimize well performance and minimize operational risks associated with sand production in oil wells.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research.

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