International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
ISSN Online: 2349-4182 ISSN Print: 2349-5979
Received: 29-09-2024,Accepted: 30-10-2024, Published: 14-11-2024
Volume 11, Issue 11, 2024, Page No. 34-37

# Advanced design methodologies for well completion screen pipes in ultra-deep carbonate reservoirs

**Syed Murtajiz Hussain Rizvi**
Department of Petroleum Oil & Gas Engineering, Southwest Petroleum University, China

**Abstract**
Ultra-deep carbonate reservoirs, particularly those located in high-stress environments like the Tarim Basin's Fuman Block, present significant challenges for well completion systems due to extreme pressures, temperatures, and complex geomechanical conditions. This review paper explores the current advancements and design methodologies for well completion screen pipes, focusing on overcoming challenges such as sand production, reservoir subsidence, wellbore collapse, and material degradation in ultra-deep carbonate formations. It covers recent innovations in screen materials, structural designs, and sand control technologies, with a focus on tailoring solutions to the unique characteristics of carbonate reservoirs. The paper also highlights the role of numerical simulations, such as Finite Element Method (FEM) and Computational Fluid Dynamics (CFD), in optimizing screen pipe performance by predicting stress distribution, fluid flow, and sand transport behaviors. By examining current research and field data, the review provides actionable insights for improving well completion systems' durability, efficiency, and safety in ultra-deep carbonate reservoirs. The expected outcomes include enhanced well productivity, reduced operational risks, and minimized environmental impacts. The paper concludes by outlining future directions for continued research, emphasizing real-time diagnostic technologies, adaptive completion systems, and improved modeling techniques.

**Keywords:** Ultra-deep carbonate reservoirs, well completion screen pipes, hydrocarbon extraction, geomechanical challenges, high-pressure, high-temperature (HPHT) conditions, sand production control

## Introduction

Ultra-deep carbonate reservoirs, particularly in high-stress regions like the Tarim Basin's Fuman Block, present complex challenges for hydrocarbon extraction due to their extreme depths, high-pressure, high-temperature (HPHT) conditions, and geomechanical variability. These reservoirs, often exceeding 7,500 meters in depth, subject well completion systems to stress and thermal cycles that exceed conventional design specifications (Chartier *et al*., 2018) [6]. The fractured nature of carbonate rocks, with heterogeneously distributed porosity and permeability, complicates well completion further by introducing flow irregularities that exacerbate sand production, causing erosion, clogging, and potential wellbore collapse (Y. B. Tang *et al*., 2019) [24]

Well completion screen pipes are vital for ensuring well integrity and maximizing production from such reservoirs. These screens must be designed to withstand the combined challenges of sand production, stress-induced deformation, and HPHT conditions. Given the high risk of operational failure in ultra-deep carbonate reservoirs, optimization of screen pipe design has become a focal point of research and development. This review consolidates the latest advancements in screen pipe material selection, structural design, sand control mechanisms, and simulation methodologies, offering an actionable framework for optimizing well completion systems in carbonate reservoirs.

## Reservoir Characteristics and Completion Challenges

### 1. Geological and Geomechanical Overview

Carbonate reservoirs exhibit heterogeneous pore structures with varying permeability due to fractures and diagenetic processes. These variations, combined with the high in-situ stresses of ultra-deep formations, create challenges in predicting and managing wellbore stability and flow efficiency (Cai *et al*., 2024) [5]. In ultra-deep settings like the Fuman Block, stress-induced deformation and wellbore collapse have been identified as major concerns (Wang *et al*., 2024) [26] Reservoir compaction exacerbates these problems by increasing lateral stresses on well completions, leading to rapid screen degradation and a decrease in well integrity (AL-Aamri *et al*., 2019; Velilla *et al*., 2024) [2, 25]

The integration of geomechanical modeling and real-time monitoring into drilling operations led to significant reductions in non-productive time (NPT) by enhancing drilling performance, which included improvements in penetration rates and overall wellbore quality, ultimately achieving well objectives more efficiently (Baghdadi *et al*., 2024) [4]. Geomechanical models are instrumental in addressing mechanical instabilities in wellbores, such as those caused by weak shales and porous sandstones. For instance, in the Middle East offshore exploration field, geomechanical modeling helped optimize mud weight design, leading to successful well delivery without mechanical instability issues (Saber *et al*., 2024) [19]

### 2. Sand Production and Erosion Control Challenges

Sand production in carbonate reservoirs is a significant challenge due to the high fracture permeability and complex fluid dynamics that can mobilize fine sands. This phenomenon can lead to erosion of screen materials, blockages, and even catastrophic failure of well completions. The issue is exacerbated by the presence of natural fractures and weak zones in carbonate formations, which can lead to mechanical failure and the production of solid debris. Effective sand management and control strategies are crucial to mitigate these risks and ensure the longevity and productivity of wells.

**Mechanisms of Sand Production**

Solids production in the carbonate reservoir was linked to the geomechanical behavior of the rock and fractures during production, particularly in the presence of natural fractures and weak zones, which led to anomalous well head flowing pressure behavior and a progressive reduction in gas rate due to choke plugging by debris. The modeling study provided valuable insights into the mechanisms of solid production in both open hole and cased/perforated wells, which can inform future completion options and critical drawdown pressure strategies to mitigate solids production risks in similar carbonate reservoirs (Pourpak *et al*., 2024) [18]. Sand production is more pronounced in multiphase flow conditions, such as gas-water flows, where the interaction between different phases can increase the mobilization of sand particles (Shabdirova *et al*., 2022) [21].

**Sand Control Techniques**

The selection of appropriate sand screens is critical. Screens should be chosen based on sand retention performance and the capacity to handle fluid flow. Advanced materials like ceramics and metallic alloys are often used to enhance durability and resistance to erosion (Abduljabbar *et al*., 2024) [1]. Utilizing standalone screens with autonomous inflow control devices can help balance pressure and adjust fluid flow, effectively managing sand influx and preventing erosion (Khan *et al*., 2024) [12]

**Sand Management Strategies**

Numerical models, such as the SEAD1 framework, are used to predict sand transport, erosion rates, and deposition patterns. These models help in determining optimal production rates and minimizing risks associated with sand production(Santhamoorthy *et al*., 2024) [20] Acoustic leak monitoring systems can detect sand production thresholds, allowing for proactive measures to prevent erosion. Remedial actions like re-gravel packing and periodic wellbore cleanups are also recommended to manage sand-related issues (Khan *et al*., 2024) [12]

**Innovative Approaches**

These beads can be used as gravel pack materials to reduce mechanical failure risks. They expand under reservoir conditions, increasing radial stress and reducing hoop stress, thereby mitigating sand production risks (Han & Liang, n.d.). Coupled Computational Fluid Dynamics and Discrete Element Method (CFD-DEM) simulations provide insights into sand production mechanisms at the micro-level, aiding in the development of more accurate prediction models (Shabdirova *et al*., 2022) [21]. Computational Fluid Dynamics (CFD) simulations have shown that traditional sand control models, which are often based on sandstones or homogeneous formations, do not adequately predict the erosion and clogging behavior in fractured carbonate reservoirs, sand control technologies, such as expandable metal sleeves, multi-layered gravel packs, and filter-controlled screens, are critical for improving sand control in these reservoirs (Abduljabbar *et al*., 2024) [1] These solutions reduce the frequency of well interventions and improve operational efficiency.

**3. Operational and Environmental Constraints**

The extreme operational conditions in ultra-deep carbonate reservoirs require completion materials that are resistant to both mechanical wear and corrosive environments. The presence of $CO_2$, $H_2S$, and high salinity fluids intensifies the risk of corrosion, leading to premature failure of well completion systems (Craig *et al*., 2023) [7] Recent studies have emphasized the need for high-strength, corrosion-resistant materials such as high-chromium alloys and composite coatings to ensure the longevity of well screens under these harsh conditions (Wu *et al*., 2023) [27].

**Literature Review: Current Approaches and Innovations**

**1. Material Selection and Structural Design**

Recent advancements in material science have significantly impacted the design of well completion screen pipes. Materials such as Inconel, titanium alloys, and high-chromium steels have been identified for their superior strength, fatigue resistance, and corrosion resistance in HPHT environments (Ong *et al*., 2024; Zhao, 2019) [16, 28] Additionally, novel coatings and composite materials are being explored to further improve durability, particularly in the presence of aggressive corrosive fluids (Gharbawi *et al*., 2018) [9]

Studies have also investigated the use of expandable metal sleeves, which can be deployed in a collapsed state and then expanded once inside the wellbore, providing a flexible and efficient solution to support well completion under varying stress conditions (Feng *et al*., 2024) [8] Furthermore, filter-controlled screen assemblies, which use finer filtration mechanisms, have shown promise in enhancing fluid flow and minimizing the risk of sand production (NN, 2023) [15]

**2. Sand Control Mechanisms and Predictive Modeling**

Advanced sand control strategies, such as multi-layered gravel packs and novel screen configurations, have been designed specifically for carbonate reservoirs. These designs utilize predictive models that incorporate key reservoir parameters such as fracture density, pore pressure, and particle size distribution to forecast sand production and adjust screen design accordingly (Abduljabbar *et al*., 2024; Maciel *et al*., 2018) [1, 14] Recent research has demonstrated that multi-layer screen designs can reduce sand ingress by up to 40%, improving screen stability and reducing the need for frequent well interventions (Soroush *et al*., 2020)

Predictive modeling, based on geomechanical data and CFD simulations, has become essential in anticipating sand production behavior. Incorporating these models into screen design allows for a more targeted approach to sand control and increases the efficiency of completion systems (Gharieb *et al*., 2024; Shabdirova *et al*., 2022) [10, 21]

**3. Numerical Simulation Techniques**

Simulation tools, including Finite Element Method (FEM) and Computational Fluid Dynamics (CFD), have revolutionized the way engineers' approach well completion design in ultra-deep carbonate reservoirs. These tools allow for the modeling of stress distribution, fluid dynamics, and sand transport patterns specific to carbonate formations, leading to more precise and effective screen designs (Liu *et al*., 2022) [13] While traditional models were based on sandstone reservoirs, recent adaptations of FEM and CFD to carbonate reservoirs have incorporated unique factors such as anisotropic stress fields and fracture-induced flow behaviors (Peng *et al*., 2023) [17]

Studies have shown that combining FEM with reservoir compaction models can predict the effects of reservoir deformation on wellbore stability, providing insights into how stress concentrations influence the performance of completion screens under dynamic conditions (Sun, 2022) [22] These advances in simulation technology are critical for optimizing well screen designs to withstand the complex forces at play in ultra-deep carbonate reservoirs.

**Methodology for Optimizing Screen Pipe Design**

**1. Field Data Analysis and Geomechanical Modeling**

An effective well completion screen design begins with a comprehensive analysis of field data, including seismic surveys, well logs, and geomechanical modeling. These data help identify key reservoir characteristics such as fracture networks, stress distributions, and pore pressure gradients, which are critical for determining screen pipe material properties, aperture sizes, and screen configurations (Maciel *et al*., 2018) [14] Geomechanical modeling further helps in predicting how the reservoir will behave under production conditions, providing insights into potential risks such as wellbore collapse or screen degradation.

**2. Laboratory Testing for Material and Structural Durability**

Laboratory tests under HPHT conditions are essential for validating the performance of screen materials and structural configurations. Testing is conducted to assess erosion resistance, corrosion resistance, and structural integrity under simulated reservoir conditions (Feng *et al*., 2024; H. Tang *et al*., 2024) [8, 23]. These tests ensure that screen designs are suitable for deployment in ultra-deep carbonate reservoirs, where high pressures, extreme temperatures, and corrosive fluids can rapidly degrade conventional materials.

**3. Numerical Simulations**

Numerical simulations, using advanced FEM and CFD models, are employed to simulate stress distribution, fluid flow, and sand transport patterns in carbonate reservoirs. These simulations allow for optimization of screen designs by identifying areas of potential failure and predicting the impacts of reservoir deformation, pressure differentials, and fracture-induced flow dynamics on screen performance (Sun, 2022) [22]

**Expected Outcomes and Industry Implications**

The implementation of optimized well completion screen designs is expected to yield several significant benefits:

- **Enhanced Well Productivity**: Advanced sand control designs reduce sand production, thereby improving flow efficiency and increasing recovery rates (AS, 2024)
- **Improved Operational Efficiency and Safety**: The use of durable materials, combined with real-time monitoring systems, extends the operational life of screens, minimizes downtime, and enhances overall well integrity (H. Tang *et al*., 2024) [23]
- **Reduced Environmental Impact**: Advanced fluid management and monitoring technologies reduce the risk of wellbore failure, mitigating environmental hazards associated with oil and gas extraction (Liu *et al*., 2022) [13]

**Conclusion and Future Directions**

The optimization of well completion screen pipe designs for ultra-deep carbonate reservoirs remains a critical focus for the oil and gas industry. Advances in material science, predictive modeling, and simulation techniques are offering new pathways to address the unique challenges posed by these environments. Future research should continue to explore real-time diagnostic technologies, adaptive completion systems, and refined FEM and CFD models to further enhance screen design accuracy and well completion efficiency. With ongoing innovation, the industry can ensure safer, more sustainable, and more productive extraction from ultra-deep carbonate reservoirs.

**References**


1. Abduljabbar A, Amadi A, Mohyaldinn ME, Ridha S, Younis O, Alakbari FS. Sand screens application and performance for sand control: A review of selection criteria, screen materials, and causes of failure. Heliyon, 2024, 10(10). doi: 10.1016/j.heliyon.2024.e30731.
2. Al-Aamri M, Mahajan S, Mukhaini H. Geomechanical assessment of compaction related well integrity risks for a large field in Sultanate of Oman. Presented at: SPE/IADC Asia Pacific Drilling Technology Conference and Exhibition, Kuala Lumpur, Malaysia, 2019. doi: 10.2118/197308-MS.
3. AS KT. Completion design to prevent the production of sand in a well by using suitable equipment. Petroleum & Petrochemical Engineering Journal,2024:8(1):1-7. doi: 10.23880/ppej-16000376.
4. Baghdadi AA, Vossen J, Sen S, Chakrabarti P, Podder T, Mitra S, Alabdulmuhsin E. Delivering challenging wells with reduced NPT using real-time geomechanics: A Middle Eastern perspective. Presented at: International Petroleum Technology Conference, Dubai, UAE, 2024, 12-14. doi: 10.2523/IPTC-23347-MS.
5. Cai W, Jiang S, Liu H. Study on the mechanism of stress sensitivity changes in ultra-deep carbonate reservoirs. Appl Sci,2024:14(6):2322. doi: 10.3390/app14062322.
6. Chartier MA, Miller SM, Kaiser TM. Addressing thermal loading uncertainties for liner design. Presented at: SPE/IADC Drilling Conference and Exhibition, Amsterdam, Netherlands, 2018, 27-29. doi: 10.2118/193356-MS.
7. Craig B, Rowe A, Warmack M, Doll TE, Stevens C, Connors KC. Guidelines for the selection of corrosion resistant alloys for CCS and CCUS injection wells. Int J Greenhouse Gas Control,2023:129:103988. doi: 10.1016/j.ijggc.2023.103988.
8. Feng X, Zhao K, Zhang J, Wang J. Carbonate reservoir fracture-cavity system identification based on the improved YOLOv5s deep learning algorithm. Energy Sci Eng,2024:12(6):2643-2660. doi: 10.1002/ese3.1773.
9. Gharbawi S, Saqib T, Kaouche S, Sabri AM, AL-Mehairi O, Mutairi A. Optimizing the completion design of a maximum reservoir contact well for enhanced deliverability, monitoring and accessibility. Presented at: SPE/IADC Drilling Conference and Exhibition, Istanbul, Turkey, 2018, 12-14. doi: 10.2118/192776-MS.

10. Gharieb A, Gabry MA, Algarhy A, Elsawy M, Darraj N, Adel S, *et al*. Revealing insights in evaluating tight carbonate reservoirs: Significant discoveries via statistical modeling. An in-depth analysis using integrated machine learning strategies. Presented at: SPE/IADC Drilling Conference and Exhibition, Abu Dhabi, UAE, 2024, 7-8. doi: 10.2118/219199-MS.
11. Han Y, Liang F. Mitigation of sand production risk using thermally expandable polymeric beads. Proceedings of the 56th US Rock Mechanics / Geomechanics Symposium, Chicago, IL, 2022, 19-22. doi: 10.56952/ARMA-2022-0053.
12. Khan JA, Cai B, Zhang Y, Zainal AZB, Shao X, Wang C, Maoinser MAB. Smart standalone screen completion strategy for sand control by balancing fluid influx: A review on sand retention for screen selection, acoustic sand leak detection, and sand removal methods from subsurface to surface. Powder Technol,2024:436:119477. doi: 10.1016/j.powtec.2024.119477.
13. Liu S, Wang H, Lan W, Liu Y, Che J, Ma S. Repairing damaged screen pipes with tube hydroforming: Experiments and feasibility analysis. Machines,2022:10(5):391. doi: 10.3390/machines10050391.
14. Maciel RS, Maciel FS, Pereira FA, Ribeiro DC, Aldeia W, Martins AL, Bloch M, Ferreira MV. Study of carbonatic scale in completion tools through modeling and simulation techniques. Presented at: SPE/IADC Drilling Conference and Exhibition, Paris, France, 2018, 20-21. doi: 10.2118/190703-MS.
15. NN K. Completion design in petroleum well with two different reservoirs. Petroleum & Petrochemical Engineering Journal,2023:7(3):1-7. doi: 10.23880/ppej-16000359.
16. Ong GSH, Ho A, Udin R, Chan L, Chia BS, Vattanapornpirom K, *et al*. Overcoming challenges of a deep, HP-Ultra HT and high contaminants carbonate well: Pioneering well design of the largest HPHT gas field development in Malaysia. Presented at: SPE/IADC Asia Pacific Drilling Technology Conference and Exhibition, Kuala Lumpur, Malaysia, 2024, 6-8. doi: 10.2118/219661-MS.
17. Peng Y, Fu G, Sun B, Chen J, Zhang W, Ren M, *et al*. Data-driven collapse strength modelling for the screen pipes with internal corrosion defect based on finite element analysis and tree-based machine learning. Ocean Eng,2023:279:114400. doi: 10.1016/j.oceaneng.2023.114400.
18. Pourpak H, Su K, Bikong C, Rammal H, Bigno Y, Xi G, *et al*. Solids production geomechanical evaluation in a fractured/vuggy carbonate reservoir from Abu Dhabi offshore field: Postmortem analysis and advanced finite element simulations. Presented at: 58th U.S. Rock Mechanics/Geomechanics Symposium, Golden, CO, 2024, 23-26. doi: 10.56952/ARMA-2024-0614.
19. Saber R, Qahtani F, Baghdai A, Sen S, Chakrabarti P. Geomechanics-aided successful execution of a challenging build-up section through mixed lithologies. Presented at: SPE/IADC Drilling Conference and Exhibition, Abu Dhabi, UAE, 2024, 7-8. doi: 10.2118/219248-MS.
20. Santhamoorthy PZ, Williams B, Sambath K, Subramani HJ, Cremaschi S. An integrated framework for sand handling in wellbore and surface facilities. Geoenergy Sci Eng,2024:239:212947. doi: 10.1016/j.geoen.2024.212947.
21. Shabdirova A, Khamitov F, Kozhagulova A, Nguyen M, Zhao Y. Sand production in two-phase gas-water flow. Presented at: SPE/IADC Drilling Conference and Exhibition, New Orleans, LA, 2022. doi: 10.2118/212054-MS.
22. Sun B. Optimization design of screen pipes hole arrangement parameter based on collapse strength. Thin-Walled Struct,2022:171:108647. doi: 10.1016/j.tws.2021.108647.
23. Tang H, Jia C, Lu H, Deng Y, Zhu B. Numerical simulation of residual oil distribution characteristic of carbonate reservoir after water flooding. Front Earth Sci,2024:12:1395483. doi: 10.3389/feart.2024.1395483.
24. Tang YB, Li M, Liu XJ, Zhang WS, Qi T, Wei MJ. Pore-scale heterogeneity, flow channeling and permeability: Network simulation and comparison to experimental data. Physica A,2019:535:122533. doi: 10.1016/j.physa.2019.122533.
25. Velilla JDU, Fontoura SAB, Melo DDEF, Braga JJVV, Dias R, Okama CS. Numerical approach to evaluate cement sheath barrier during reservoir compaction in vertical oil wells. Presented at: 58th U.S. Rock Mechanics/Geomechanics Symposium, Golden, CO, 2024, 23-26. doi: 10.56952/ARMA-2024-1058.
26. Wang X, Zhou B, Wen L, Qin H, Yang J, Qin G, *et al*. A systematic approach to drilling performance improvement and risk reduction in horizontal wells. Presented at: International Petroleum Technology Conference, Dubai, UAE, 2024, 12-14. doi: 10.2523/IPTC-23496-MS.
27. Wu B, Qiu P, Shi S, Zhang Y, Huang X, Nie Z. Study on anti-corrosion performance and applicability of self-healing coating for tubulars in CO2/H2S environment. Presented at: SPE/IADC Drilling Conference and Exhibition, Houston, TX, 2023, 23-25. doi: 10.2118/214641-MS.
28. Zhao X. Research and application of gravel-packing flow-regulation water-control screen completion technique in horizontal wells. IOP Conf Ser: Earth Environ Sci,2019:227:042034. doi: 10.1088/1755-1315/227/4/042034.