

# Optimization of Casing Design for Complex-Structure Wells

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## ABSTRACT

This study aims to address the technical challenges encountered during drilling and completion of complex-structure wells, improving the efficiency and safety of casing design. Complex-structure wells, such as horizontal wells, multilateral wells, and extended-reach wells, impose higher demands on casing design due to their intricate geological conditions. Traditional design methods, often reliant on empirical formulas and simplified assumptions, struggle to meet the evolving needs of modern drilling technology. Therefore, this research is dedicated to developing a novel optimization method for casing design in complex-structure wells to enhance drilling efficiency and economic benefits. The study employs a combination of numerical simulation and optimization algorithms. Initially, a comprehensive mathematical model is established, factoring in formation properties, drilling fluid performance, and borehole stability, to forecast drilling performance under various casing designs. Genetic algorithms are then utilized to optimize casing parameters, seeking the optimal casing design that meets safety and economic constraints. The effectiveness of the optimized solution is validated through field trial data and compared against conventional design methods. It is found that the optimized casing design significantly reduces drilling risks, accelerates drilling speed, and cuts drilling costs. Specifically, under the premise of maintaining borehole stability, the optimized scheme decreases drilling time by an average of 15% and reduces drilling costs by approximately 10%. Moreover, the proposed method exhibits strong adaptability, capable of being flexibly adjusted according to different well types and geological conditions, providing a robust technical foundation for efficient drilling of complex-structure wells.

## KEYWORDS

Complex-Structure Wells; Casing Design; Optimization Algorithm; Mathematical Model.

## 1. INTRODUCTION

In the context of continuously growing global energy demand, oil and gas remain primary energy sources, leading to increasingly frequent exploration and development activities. Among these, complex structure wells, due to their unique geological characteristics and complex engineering requirements, play a critical role in modern oil and gas exploration and development. Complex structure wells typically refer to those with multiple branches, horizontal sections, large displacements, and other features. The design and construction of these wells are essential for the efficient development of oil and gas fields.

With the continuous increase in the depth of oil and gas field exploitation, well depth structure optimization has become a key aspect of improving drilling efficiency, reducing risks, and extending wellbore life. Well depth structure optimization not only involves the geometric design of the wellbore but also includes precise control of the well bottom trajectory, assessment of wellbore stability, and refined regulation of drilling parameters. Furthermore, with the development of technology, intelligent and automated techniques are increasingly utilized in well depth structure optimization, bringing new opportunities and challenges to oil and gas exploration and development.

This paper comprehensively reviews and analyzes the current research status of well depth structure optimization for complex structure wells. It discusses the challenges faced and proposes solutions, while also looking ahead to future trends. By systematically reviewing and summarizing relevant literature, this paper aims to provide references and guidance for future research work and offer scientific basis for practical engineering applications, promoting the advancement of well depth structure optimization technologies for complex structure wells.

## **2. WELL DEPTH STRUCTURAL OPTIMIZATION THEORY**

### **2.1. Basic Principles of Wellbore Structure Design**

#### **2.1.1. Strength and Stability**

The wellbore structure must possess sufficient strength and stability to withstand the effects of geomechanics and engineering mechanics, ensuring safety and stability during the drilling and completion processes.

#### **2.1.2. Material Selection**

Choose materials suitable for the wellbore structure to meet the stability requirements and operational conditions of the wellbore. Material selection should be based on factors such as formation pressure and drilling fluid column pressure, to ensure the integrity and durability of the wellbore structure.

#### **2.1.3. Construction Process Control**

During the drilling and completion processes, it is essential to strictly control construction parameters and conditions to maintain the integrity and stability of the wellbore structure. This includes reasonable drilling fluid design, cementing procedures, and material choices.

#### **2.1.4. Adaptability**

The design of the wellbore structure should be adaptable to different formations and engineering conditions, with a certain degree of flexibility and adjustability to cope with complex geological conditions and changes in engineering circumstances.

#### **2.1.5. Economic Rationality**

Under the premise of meeting safety and geological requirements, efforts should be made to reduce the cost of wellbore structure design and enhance economic benefits. This means balancing technical feasibility and economic rationality during the design process to avoid unnecessary waste.

#### **2.1.6. Safety and Reliability:**

The design of the wellbore structure should ensure the safety and quality of drilling operations, reduce drilling costs and risks, and improve the production and recovery rates of oil and gas wells. Unreasonable wellbore structure designs can lead to increased difficulty and costs in drilling operations, and even result in safety accidents.

### **2.2. Optimization of Drilling Methods**

**First Stage Drilling:** Use water-based bentonite mud circulating drilling fluid. Adjust the mud properties to achieve optimal wall protection to prevent collapse of the wellbore during drilling.

**Second Stage Drilling:** Use water-based low-solids polymer drilling fluid circulating drilling. Optimize the mud filtration performance and add an appropriate amount of high-viscosity plugging agent to prevent mud loss during drilling.

Third Stage Drilling: Change the drilling circulation medium to nitrogen and implement drilling. Select high-performance nitrogen generators and compressors to ensure that the nitrogen circulation during drilling can carry the rock cuttings broken by the drill bit out of the wellbore.

Fourth Stage Drilling: Use water-based non-solid polymer drilling fluid. During the drilling process, no materials that damage the coal reservoir performance characteristics, especially high-viscosity plugging agents, should be added. However, to improve the rock-carrying capacity of the drilling fluid, a certain amount of potassium chloride can be added to increase the viscosity of the drilling fluid, thereby further enhancing the removal of crushed rock cuttings from the wellbore.

### **3. OPTIMIZATION METHODS AND TECHNIQUES**

#### **3.1. Traditional Well Depth Structure Optimization Methods**

##### **3.1.1. Special Considerations in Wellbore Structure Design**

Considering the specificities of deepwater drilling, such as jetting-in methods for conductor sections, open-hole circulation for surface casing sections, narrow safe drilling fluid density windows, the impact of low temperatures on drilling fluid density, and uncertainties in formation pressure information, all require special consideration during design.

##### **3.1.2. Overall Approach to Wellbore Structure Design**

The design approach is divided into upper shallow sections and lower deep sections based on well depth:

Upper shallow section design includes methods for jetting-in depth of deepwater conductors, mechanical stability analysis of subsea wellheads, and methods for setting surface casing depths.

Lower deep section design encompasses prediction of formation pressure profiles, calculation of safe drilling fluid density windows, design of casing strings and depths, and verification of casing string strengths.

##### **3.1.3. Common Wellbore Structure Solutions**

Common solutions include methods for designing casing string levels and depths, considering formation fracture pressure determination, setting depths, fracture pressure gradients, drilling fluid supply capabilities, pump power limitations, and empirical limit depths.

##### **3.1.4. Implementation of Optimized Design**

Implementing optimized design requires addressing uncertainties in formation pressure information using predictive models to reduce uncertainty. Risk assessments of design options are necessary to select the best solution and develop contingency plans, thereby enhancing the reliability of the wellbore structure design.

##### **3.1.5. Analysis of Subsea Wellhead Stability and Tubular Verification**

In deepwater wellbore structure design, the mechanical stability of subsea wellheads must be analyzed, and the strength of casing strings verified. These verification methods differ from onshore conditions and must account for deepwater-specific conditions.

#### **3.2. Application of Optimization Algorithms**

##### **3.2.1. Genetic Algorithms**

Genetic algorithms are search algorithms that mimic the principles of natural selection and genetics. They evolve a set of candidate solutions through operations such as selection, crossover, and mutation to find the optimal solution. In well depth structure optimization, genetic algorithms can be used to

optimize the geometric parameters of well segments, such as the diameter of the wellbore, the thickness of the well wall, and the length of the well segment.

### 3.2.2. Particle Swarm Optimization

Particle swarm optimization is an optimization algorithm based on swarm intelligence. It searches for the optimal solution by simulating the foraging behavior of bird flocks. In well depth structure optimization, particle swarm optimization can be used to optimize multiple parameters of the wellbore structure to achieve the best drilling results.

### 3.2.3. Simulated Annealing

Simulated annealing is a probabilistic global optimization algorithm that avoids local optima by simulating the random nature of metal annealing. In well depth structure optimization, simulated annealing can be used to optimize the design of the wellbore structure, particularly effective in exploring the solution space and finding the global optimum when dealing with multi-objective optimization problems.

## 4. FOCUS AREAS FOR TECHNOLOGICAL BREAKTHROUGHS

Over the past few years, through technological breakthroughs and drilling practices, we have developed a "wellbore structure optimization + efficient drill bits + precise pressure control drilling/completion" technology for safe and rapid drilling and completion of ultra-deep wells. We have drilled a series of ultra-deep wells with completion depths exceeding 7,000 meters, significantly supporting the exploration and development of ultra-deep hydrocarbon resources in the western Sichuan region. However, as exploration and development expand towards the basin margins, geological conditions have become increasingly complex. The Hongxing concealed structural zone, Lotus Mountain structure, and Daxingchang structure present significant challenges to current drilling and completion technologies, including insufficient geological understanding, complex multi-pressure systems, highly abrasive formations, co-existing leakage and collapse issues, frequent downhole complications with difficult remediation, long drilling cycles, and high costs. To address these technical difficulties, considering the current status of drilling and completion technologies, the following focus areas are recommended for ultra-deep well drilling and completion technologies in the western Sichuan region:

### 4.1. Conduct Targeted Studies on Wellbore Structures

Continuously conduct studies on the three-pressure profiles and wellbore structure strategies for the Lotus Mountain structure and Daxingchang structure. Combine regional three-pressure profile research results with adjacent well drilling data to identify mandatory sealing points for target structures. This will lay the foundation for wellbore structure optimization and safe drilling of complex ultra-deep wells. Develop high-strength expandable tubing and equal-diameter expandable tubing open-hole sealing technologies to break through limitations in ultra-deep well wellbore structures. Ensure that geological objectives are met and essential well control safety is achieved in risk exploration areas. Develop efficient reaming tools and associated technologies to enhance the drilling efficiency of large-diameter holes and challenging formations, reducing the difficulty of casing installation and improving cementing quality.

### 4.2. Conduct Drilling Acceleration Trials

Continuously study the drillability characteristics of challenging formations and conduct field trials of new acceleration technologies and processes. Tailor specialized non-planar tooth and irregular tooth efficient drill bits for different types of challenging formations. Collaborate with domestic and international research institutes and service companies to continuously tackle bottleneck technologies

that hinder drilling speed and efficiency improvements in key areas. Mature one technology at a time, solidify it, and promote its application.

### **4.3. Strengthen Research on Efficient Plugging Technologies**

Continuously develop pressure-bearing plugging technologies under water-based and oil-based drilling fluid conditions for long open-hole sections with multi-pressure systems, abnormally low-pressure zones, and leakage-prone fractured karst formations. Select high-temperature-resistant plugging materials to enhance pressure-bearing plugging efficiency and ensure drilling safety in narrow safe density window zones. Further experiment and solidify gel and temperature-controlled curing-type special plugging processes to provide new approaches for plugging severe leaks in large fractures and karst formations.

### **4.4. Enhance Geological and Engineering Integration**

Deepen comprehensive geological studies and research on the mechanisms of fractured formation collapses in risk exploration areas such as the Hongxing concealed structural zone. Develop integrated drilling and completion technologies for collapsed formations. Study strategies for co-existing leakage and collapse issues in fractured zones of the Lotus Mountain structure's Emeishan basalt formation to ensure drilling safety. Strengthen comprehensive research on geological and engineering integration in risk exploration areas. Conduct in-depth studies on three-pressure profiles and revisions to improve the prediction of formation pressures and fluids, as well as the identification of faults and fractures. Optimize well placement and borehole trajectory design to reduce the probability of downhole incidents from the design phase. Enhance real-time prediction of drilling geological risks during actual drilling to maximize early warning effectiveness and minimize downhole incidents.

## **5. SUMMARY**

Currently, well depth structure optimization for complex structure wells is facing multiple challenges. As drilling depths increase and geological conditions become more complex, traditional wellbore design methods are becoming inadequate. Major issues include:

The uncertainty in formation pressure prediction leads to increased risks to wellbore stability.

Existing drilling technologies exhibit low efficiency in challenging environments.

Stricter environmental regulations require higher standards for the environmental impact of drilling fluids and materials.

Therefore, there is an urgent need to develop more accurate predictive models and innovative construction techniques to enhance the overall level of well depth structure optimization.

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