

Study on Water Control Effect of Screen Pipe in Completion Stage of High Aquifer in Oilfield

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ABSTRACT This study investigates the effectiveness of screen pipe completion technologies combined with advanced thixotropic packer sealing for water control in high aquifer oilfields. The design integrates optimized completion strings, multistage sand-carrying fluids, and fine water-control screens to regulate flow resistance, suppress bottom-water intrusion, and enhance sand control. Numerical simulations demonstrate that narrowing screen gaps to 0.3 mm can reduce water cut by up to 30%, providing a robust basis for field optimization. Field trials show significant improvements: daily oil production increased by 75.6% in East Hebei Oilfield and cumulative production increased by 36,000 tons in four horizontal wells at Northwest Oilfield, with extended water-free production periods up to 448 days. Despite higher initial costs, long-term economic benefits justify adoption. The framework supports integration with real-time downhole monitoring and adaptive control systems, leveraging sensor-based data acquisition and process optimization. This provides an engineering-oriented solution for stable, efficient, and cost-effective oilfield production under high water cut conditions, bridging advanced completion technology with in-situ sensing and operational monitoring.

INDEX TERMS screen pipe completion, water control, high aquifer oilfield, adaptive monitoring systems

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

WITH the advancement of global oilfield development, most fields have entered the high-water-cut production phase, with water cut levels in many reservoirs exceeding 90%. This trend necessitates innovative, high-efficiency textile filter media capable of separating complex oil-water emulsions. At this stage, water production from wells rises dramatically, leading to escalating production costs and severe corrosion of pipelines and equipment. These factors elevate the risk of leakage incidents and significantly disrupt normal oilfield operations. For instance, during the high water cut period in certain oilfields, producing one ton of crude oil may require the simultaneous production of several tons, or even dozens of tons, of water. This scenario substantially increases pumping energy consumption, sharply raises production costs, and drastically reduces economic efficiency.

Screen completion technology is widely adopted in oilfield development due to its cost-effectiveness and efficient sand control. However, in high water cut formations, the water control efficiency of traditional screen completion technology often fails to meet production demands. This is particularly true for offshore oilfields, where screen-based completions account for over 60% of horizontal wells. The

unique challenges of offshore operations make traditional water control measures difficult to implement, leading to rapid increases in water cut and accelerated production decline. Therefore, evaluating the water control effectiveness of screens during the completion phase in high water cut zones and enhancing their water control capability are critical for ensuring stable and increased oilfield production and improving economic efficiency.

B. RESEARCH OBJECTIVES AND SCOPE

This study aims to establish an evaluation system for screen-based water management in high water cut formations and to propose optimized screen-completed wellbore techniques suitable for such zones. The objectives include enhancing water control effectiveness, extending the water-free production period of oil wells, and achieving stable production and increased output, thereby providing valuable performance metrics for the development of highly selective, durable textile filter media used in these screens. Specific research tasks include: analyzing the suitability of various screen types for high water cut zones; optimizing process parameters for screen completion, including string design and sand-carrying fluid systems; validating screen water control effectiveness through field trials; and proposing adaptive improvement plans for screen water control technology.

based on research findings.

II. SCREEN TYPES AND WATER CONTROL MECHANISMS IN HIGH WATER CUT FORMATIONS

A. SCREEN TYPES AND APPLICABLE CONDITIONS

The main screen types used in oilfields include slotted screens, elastic screens, sintered mesh screens, and fine water-control screens. Each type exhibits distinct structural features, application requirements, and limitations regarding water control [1].

Slotted screens are produced by cutting 0.3–0.4 mm fine slots in casing or tubing. These screens have a simple structure and are suitable for medium-to-low permeability reservoirs with clay content below 15%. However, slotted screens display poor self-cleaning performance. Sand particles entering the slots can cause blockages, leading to production interruptions. In deep wells, slotted screens are susceptible to failure primarily due to high collapse loads from formation sand and significant differential pressure during production. These loads can exceed the screens' structural integrity, resulting in deformation or collapse.

Elastic screens consist of a perforated base pipe and an elastic fiber filter layer. The base pipe provides fluid flow pathways, while the elastic fiber filter layer blocks sand and regulates water entry. Elastic screen pipes are suitable for sandstone reservoirs with grain sizes larger than 0.15 mm, offering excellent sand control performance. However, prolonged flushing can cause fiber shedding, reducing sand and water control capability and shortening service life [2].

The performance of various screen pipe types is evaluated based on sand control, water control, and durability, which are criteria derived from laboratory erosion tests and statistical analysis of field failure rates, as shown in Figure 1. Durability refers to effective service life under high-velocity fluid erosion and chemical scaling, not merely mechanical strength.

Sintered mesh screens comprise a base pipe, sintered mesh, and protective sheath. The base pipe bears axial loads, while the sintered mesh acts as the sand-blocking medium, offering uniform pore size, anti-clogging properties, and high flow capacity. The protective sheath shields the sintered mesh [3]. Sintered screens are suitable for high-pressure, high-temperature reservoirs, exhibiting compressive strengths exceeding 37 MPa. However, their cost is approximately 40% higher than standard screens, increasing field development expenses.

Fine water-control screens incorporate water control devices and adjustable flow channels, leveraging the physical property differences among oil, gas, and water. By altering flow channel geometry, these screens modulate fluid kinetic energy, enabling automatic phase identification and adaptive oil-gas stabilization, including water control. Fine water-control screens are ideal for shale reservoirs with bottom water, effectively mitigating bottom water intrusion and extending water-free oil production [4]. While these screen pipes are autonomously adaptive, integrating

intelligent monitoring systems is recommended to quantify downhole water-control effectiveness, albeit with increased initial deployment costs. Table 1 summarizes the applicable conditions and water-control limitations of different types of screen pipes.

TABLE 1. Summary of Applicable Conditions and Water-Control Limitations for Different Types of Screen Pipes

Screen Pipe Type	Structural Features	Applicable Conditions	Water-Control Limitations
Slotted Screen Pipe	Fine slots (0.3–0.4 mm) cut on casing/tubing	Low- to medium-permeability reservoirs with clay content < 15%	Poor self-cleaning; insufficient strength in deep wells
Elastic Screen Pipe	Perforated base pipe + elastic fiber filter layer	Sandstone reservoirs with particle size > 0.15 mm	Long-term scouring may cause fiber shedding
Sintered Filter Screen Pipe	Base pipe + sintered filter screen + protective sheath	High-pressure, high-temperature reservoirs (pressure resistance > 37 MPa)	40% higher cost compared to ordinary screen pipes
Fine Water-Control Screen Pipe	Water-control device + adaptive flow channel	Fragmental rock bottom-water reservoirs	Optional intelligent monitoring for real-time performance tracking

B. PHYSICAL MECHANISMS OF WATER CONTROL

Flow channel resistance regulation is employed to manage water flow by adjusting the geometric properties of screen gaps or mesh apertures. For example, in the Northwest Oilfield, precision water-control screen pipes utilized flow channels with diameters less than 2.0 mm [5]. This threshold, determined by the reservoir's oil-water viscosity ratio, increases flow resistance for the lower-viscosity water phase more significantly than for oil, creating a "viscosity-sensitive" pressure drop that selectively restricts water production. Optimizing screen pipe flow parameters is crucial for practical water control enhancement.

Thixotropic material packer sealing utilizes Advanced Controlled Packer (ACP) technology to inject high-thixotropy fluids into the annulus surrounding the casing. Under high shear, the fluid exhibits low viscosity for easy injection; when shear ceases, its storage modulus increases over time, forming a high-strength, impermeable solid ring within 24 hours [6]. This process enables precise annular sectioning, as confirmed by small-amplitude oscillation tests on HTHC-based materials (high-temperature hydroxyethyl cellulose, HTHC). In offshore oilfield applications, ACP technology has demonstrated precise annular isolation, forming the foundation for subsequent water control measures.

Sintered screens, despite high initial structural integrity, are prone to local stress concentration and pore-plugging in high-salinity and high-sand-content environments, which can cause premature erosion failure. In contrast, fine water-

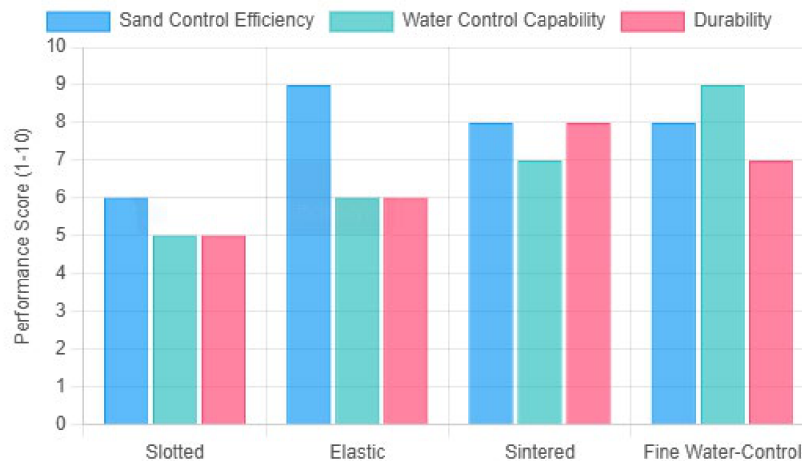


FIGURE 1. Comparison of key performance metrics for different screen types

control screens feature robust internal flow-channel designs, distributing fluid energy more evenly and reducing localized erosion. Empirical data from field trials (Case 2) indicate superior structural stability for fine water-control screens in abrasive bottom-water reservoirs, justifying their higher durability ratings.

Multi-stage sand-carrying fluid filling involves using high-viscosity sand-carrying fluids (e.g., Hydroxyethyl cellulose (HEC) polymers) to fill perforation holes, forming sand bridges that block water ingress. Subsequent low-viscosity brine fills the annulus, creating a complete sand barrier. Experiments show that multi-stage filling can enhance process efficiency by approximately 30%. Optimizing the sand-carrying fluid system and filling process improves sand and water control performance in screen completions [7]. The relationship between flow resistance and channel diameter is shown in Figure 2.

III. OPTIMIZATION OF SCREEN COMPLETION PROCESS PARAMETERS

A. COMPLETION STRING DESIGN

Completion string design is a critical aspect of screen completion technology, directly influencing water control effectiveness and well longevity. Sectional water control schemes are selected based on geological and operational requirements.

In offshore oilfields, where operational environments are complex, high reliability and sealing integrity are essential. The ACP packer combined with an integrated injection-sealing-testing tubing string is commonly used. For example, the 8HG-H8 well in Dagang Oilfield employed this system: the ACP packer enabled precise external tubing sectioning, while the integrated string provided sealing integrity and operational efficiency. Implementation of water control measures reduced water cut by 22%, demonstrating significant effectiveness [8].

Onshore oilfields may use open-hole packers combined with variable-density screen tubing, tailored to reservoir

properties. The X68-P4 well in Shengli Oilfield adopted open-hole packers for outside-the-pipe sectioning and variable-mesh-density screen pipes to accommodate permeability differences across formations, thereby achieving balanced fluid supply. Following water control implementation, the water-free production period was extended by 180 days, improving the recovery rate.

Completion strings also incorporate specialized tools, such as signal screen pipes and safety joints. Signal screen pipes provide gravel pack placement accuracy within 0.5 m, offering precise construction references. Safety joints accommodate formation compaction loads, featuring a 12-inch (approximately 305 mm) allowable axial expansion, thus maintaining mechanical integrity by compensating for reservoir-induced vertical movement [9].

B. SAND-CARRYING FLUID SYSTEM OPTIMIZATION

Optimizing sand-carrying fluid systems is vital for effective sand and water control in screen-based completions. Different polymers exhibit unique performance attributes suited to specific operational conditions. HEC, typically used at concentrations of 1.0–1.5 kg/m³ and viscosities of 80–120 mPa·s, is preferred for filling perforation holes. HEC-based fluids efficiently transport sand grains, forming stable sand bridges. With a gel break time of 4–6 hours, these fluids minimize post-filling production impact [10].

Xanthan gum-based sand-carrying fluids, with concentrations of 0.8–1.2 kg/m³ and viscosities of 60–90 mPa·s, offer high sand transport capacity and stability, making them suitable for annulus filling. Their gel break time of 2–3 hours allows rapid gel breakdown and prompt resumption of production [11]. The relationship between viscosity and polymer concentration of sand carrying fluids of different polymer types is shown in Figure 3.

Surfactant-based slurries, at concentrations of 0.5–1.0 kg/m³ and viscosities of 30–50 mPa·s, are primarily used for fluid-loss prevention in low-permeability interlayers, reducing filtration loss and enhancing sand-carrying effi-

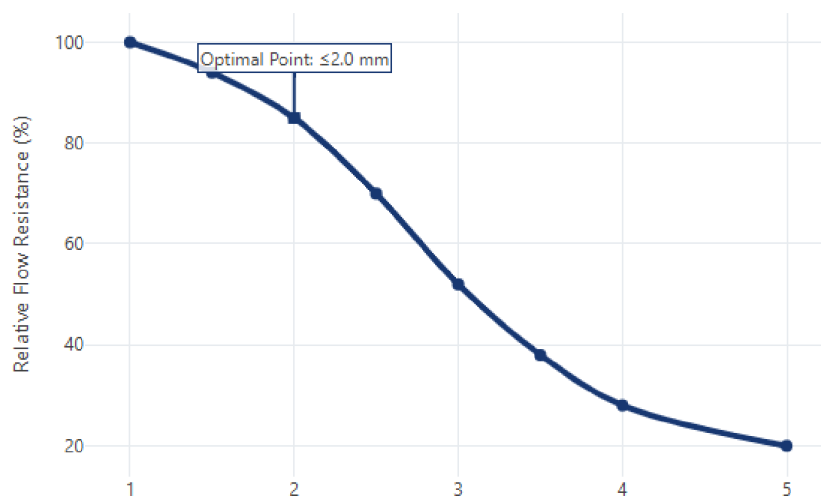


FIGURE 2. Relationship between flow resistance and channel diameter

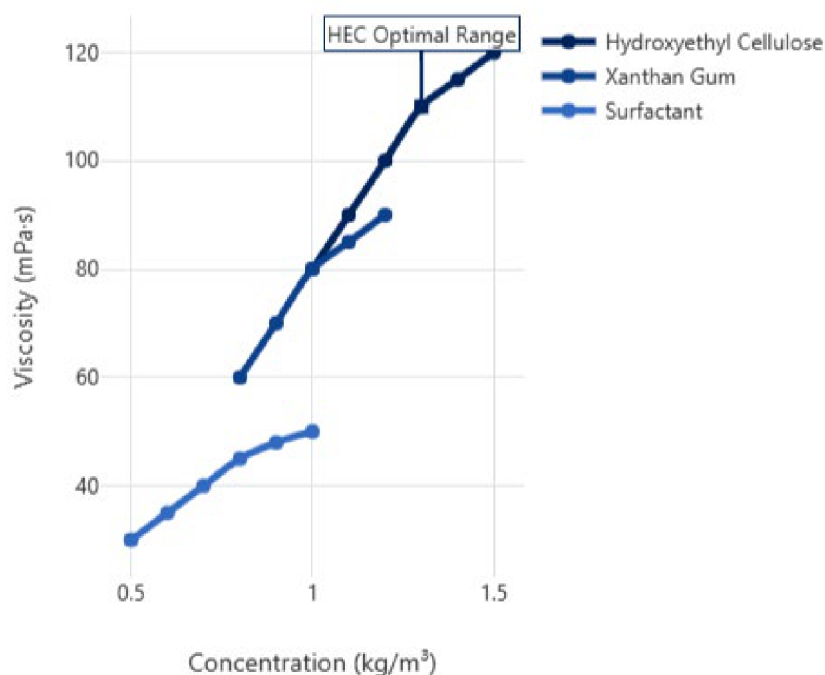


FIGURE 3. Relationship between viscosity and polymer concentration for sand-carrying fluids with different polymer types

Note: HEC = Hydroxyethyl Cellulose

ciency. Their demulsification time of 1–2 hours ensures timely reservoir protection [12]. Table 2 summarizes the performance of sand-carrying fluids with different polymer types.

TABLE 2. Performance Overview of Sand-Carrying Fluids with Various Polymer Types

Polymer Type	Concentration (kg/m ³)	Viscosity (mPa·s)	Applicable Scenarios	Gel-Breaking Time (h)
HEC	1.0–1.5	80–120	Perforation-hole filling	4–6
Xanthan Gum	0.8–1.2	60–90	Annular filling	2–3
Surfactant	0.5–1.0	30–50	Fluid-loss control in low-permeability interlayers	1–2

Note: HEC: Hydroxyethyl Cellulose.

In practice, the selection of an appropriate sand-carrying fluid system depends on reservoir geology and operational requirements. Experimental optimization of parameters such

as concentration and viscosity is essential to maximize sand and water control effectiveness in screen pipe completions [13]. The comparison of the gel breaking time of sand carrying fluids with different polymer types is shown in Figure 4.

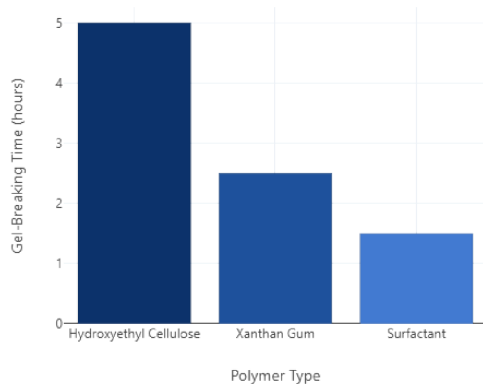


FIGURE 4. Comparison of gel-breaking time for sand-carrying fluids with different polymer types

IV. WATER CONTROL EFFECTIVENESS: NUMERICAL SIMULATION AND EXPERIMENTAL VALIDATION

A. NUMERICAL SIMULATION METHOD AND PARAMETER SETTINGS

This study employs advanced numerical simulation techniques, specifically fluid-solid coupling models, to evaluate the water control performance of screen pipes [14]. These models accurately predict fluid motion around screens by refining mesh size and boundary conditions. The global mesh size is set at 5 mm, with critical areas near the screen-reservoir interface refined to 2 mm, resulting in approximately 1.85 million computational cells. Simulation convergence is achieved when residuals for momentum and continuity equations fall below 10^{-4} , and outlet mass flow rate fluctuations remain below 0.1% over 50 iterations [15]. Optimization of mesh gap width based on water control and sand control performance is shown in Figure 5. Fluid properties, such as viscosity, density, and compressibility, are adjusted to reflect actual reservoir conditions. Structural parameters—including slot width, mesh aperture, screen length, and diameter—are continuously optimized to enhance water control efficiency [16]. For a representative scenario (reservoir pressure 20 MPa, temperature 80°C, crude oil viscosity 50 mPa·s, reservoir density 0.85 g/cm³, screen gap size 0.5 mm, mesh aperture 0.2 mm, screen length 10 m, diameter 150 mm), simulations indicate uniform fluid velocity distribution and a 5 MPa pressure gradient across the production side, resulting in a predicted water cut reduction exceeding 20% [17,18]. Further narrowing the screen gap to 0.3 mm yields up to 30% reduction in water cut. These simulation outcomes provide a robust basis for field testing and parameter optimization. The simulation and experimental results of the variation of moisture content over time are compared as shown in Figure 6. The relative

error analysis of simulation and experimental results under different parameters is shown in Figure 7.

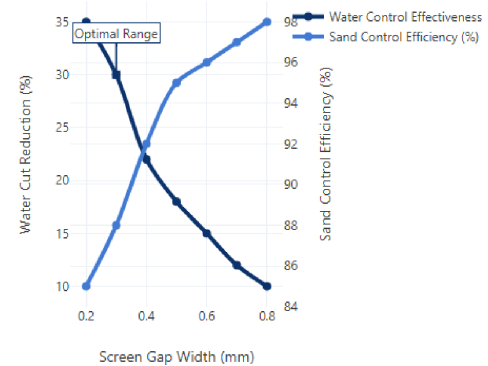


FIGURE 5. Optimization of screen gap width based on water-control and sand-control performance

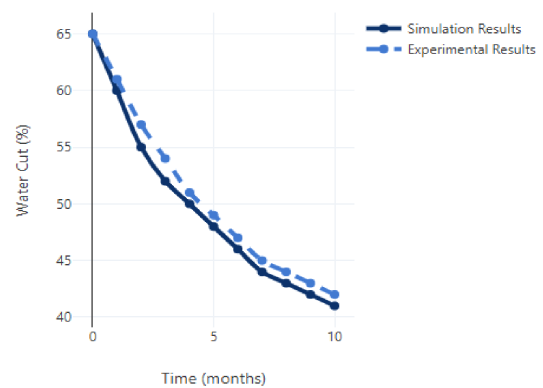


FIGURE 6. Comparison between simulation and experimental results for water cut over time

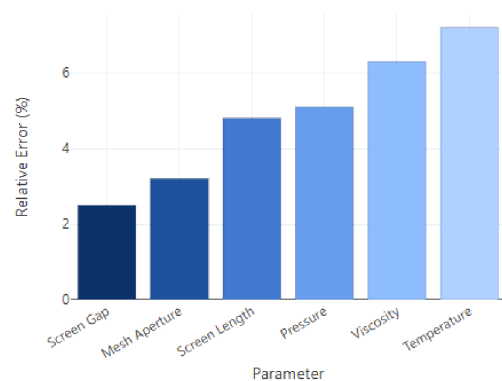


FIGURE 7. Relative error analysis between simulation and experimental results for different parameters

B. FIELD TEST CASE ANALYSIS

Comprehensive field testing was conducted to validate the practical effectiveness of screen-based water control technology in various oilfields [19]. Two representative cases are summarized below.

1) Case Study 1: Application of Screen-Based Water Control in Well T105-P1, East Hebei Oilfield

This well, located in a structurally complex fault block reservoir with high heterogeneity and sustained high water cut, posed significant production challenges. The research team implemented a completion design featuring five open-hole packers and one oil-activated expanding packer. These packers enabled precise external tubing sectioning and rapid expansion upon contact with crude oil, forming robust sealing barriers that effectively prevented water intrusion.

Real-time, 24-hour monitoring of well output revealed that, prior to intervention, the well produced 45 tons of oil per day with an 85% water cut. Post-implementation, daily oil production increased by 75.6% to 79 tons, while water cut decreased to 62%, a reduction of 27.1%. The long-term evolution of oil production and water content before and after implementation under different conditions is shown in Figure 8.

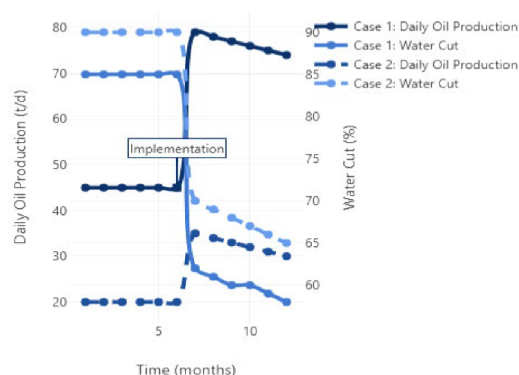


FIGURE 8. Long-term evolution of oil production and water cut before and after implementation under different cases

Production trends indicated sustained output improvement and stable low water cut. Within six months, cumulative oil production increased by nearly 5,000 tons, and cumulative water production decreased by approximately 3,000 m³. Comparative analysis of adjacent wells confirmed that those employing water control measures achieved superior production and water cut control, underscoring the technology's effectiveness and broad applicability.

2) Case Study 2: Precision Water-Control Screen Tubes, Northwest Oilfield

In response to severe water cut challenges in horizontal wells targeting clastic reservoirs, the Northwest Oilfield developed and trialed integrated precision water-control screen tubes in four wells. These screens featured flow channels with 1.8 mm diameters and operated across a pressure range of 0.5–3 MPa. Before installation, wells experienced persistently high water cut and declining production. After deploying the fine-control screens, cumulative oil production across four wells increased by 36,000 tons (9,000 tons per well), and the average water-free production period extended by 448 days. The comparison of production performance

indicators between Case 1 and Case 2 is shown in Figure 9.

Post-installation, water cut fell below 70%—a 22.2% reduction from 90% within six months—while daily oil production increased by 75% to 35 tons per day. Detailed production analysis confirmed that the adaptive flow channel and pressure regulation mechanisms effectively suppressed water intrusion and prolonged water-free production, ensuring efficient reservoir exploitation.

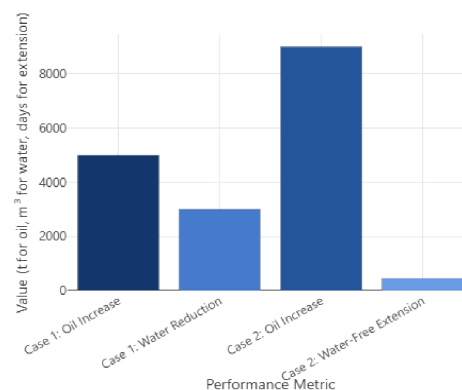


FIGURE 9. Comparison of production performance metrics between Case 1 and Case 2

V. ADAPTABILITY EVALUATION OF SCREEN-BASED WATER CONTROL TECHNOLOGY

A. RESERVOIR CONDITION COMPATIBILITY

Reservoirs exhibit diverse geological characteristics and development requirements, necessitating tailored screen types and water control technologies. Table 3 summarizes recommended screen types and key parameters for different reservoir types.

TABLE 3. Recommended Screen Pipe Types and Key Parameters for Different Reservoir Types

Reservoir Type	Recommended Screen Pipe Type	Key Parameters
Fragmental Rock Bottom-Water Reservoir	Fine Water-Control Integrated Screen Pipe	Flow channel diameter ≤ 2 mm, pressure resistance > 25 MPa
Offshore Loose Sandstone	ACP Packers + Sintered Filter Screen Pipe	Thixotropic material curing time < 12 h
High-Temperature, High-Pressure Reservoir	Elastic Screen Pipe + High-Temperature Sand-Carrying Fluid	Polymer temperature resistance $> 150^{\circ}\text{C}$, gel breaker efficiency $> 90\%$

In clastic reservoirs with bottom water, integrated fine-control water-screening tubes are recommended for their ability to adaptively regulate fluid flow and suppress bottom water intrusion. Intelligent sensors are mainly used for remote monitoring and optimization, not as prerequisites for fluid identification. For high-temperature, high-pressure reservoirs, elastic screen tubing and high-temperature sand-carrying fluids with polymer temperature resistance exceeding 150°C and gel-breaking efficiency above 90% are essential to maintain operational reliability.

B. ECONOMIC ANALYSIS

Economic evaluation considers screen tube cost, water control effectiveness, well production impact, and payback period. Precision water-control screen pipes cost an additional 1,150 CNY per meter compared to traditional screens. However, their superior water control capabilities and extended service life (2–3 times longer) significantly enhance oil recovery value.

Theoretically, a conventionally completed well producing 10 tons/day of oil at 80% water cut over five years would, when equipped with precision water-control screens, yield 12 tons/day with a 60% water cut and an extended production life of eight years. The cumulative oil production increase justifies the higher initial investment, confirming the long-term economic benefits of optimized screen-based water control technologies.

VI. CONCLUSION

This study achieved its core objective of enhancing the water control effectiveness of screen pipe completion technology in high water cut formations by establishing a robust evaluation system and proposing adaptive optimization strategies. These strategies also inform the design and material selection of advanced textile filter media for downhole separation.

Comprehensive assessment of four main screen types—slotted, elastic, sintered, and fine water-control screens—identified fine water-control screen pipes as most suitable for fragmental rock bottom-water reservoirs due to their adaptive flow channel geometry. For high-temperature, high-pressure reservoirs, elastic screen pipes paired with high-temperature sand-carrying fluids (polymer temperature resistance $> 150^{\circ}\text{C}$) were found to be optimal.

Process optimization, including completion string design and sand-carrying fluid selection, is critical. Offshore environments benefit from ACP packers with integrated tubing strings, while onshore applications utilize open-hole packers with variable-mesh-density screens. HEC (1.0–1.5 kg/m³, 80–120 mPa-s) is recommended for perforation hole filling, and xanthan gum (0.8–1.2 kg/m³, 60–90 mPa-s) for annulus filling, both chosen for controlled gel-breaking times. Validation through numerical simulations and field trials confirmed substantial performance improvements. Well T105-P1 (East Hebei Oilfield) demonstrated a 75.6% increase in daily oil production and a reduction in water cut from 85% to 62%. In the Northwest Oilfield, precision water-control screens resulted in an average cumulative oil increase of 9,000 tons per well and extended water-free production by 448 days. Despite higher initial costs, the significant long-term economic benefits fully justify the adoption of these advanced screen-based water control technologies, paralleling the cost-effectiveness observed in high-performance technical textiles for filtration and durability.

AUTHOR CONTRIBUTIONS

Conceptualization – Xiao Fan and Changyin Dong; methodology – Xiao Fan and Changyin Dong; investigation – Xiao

Fan and Changyin Dong; writing-original draft preparation – Xiao Fan and Changyin Dong. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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