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R&D and Application of Drill-Free Glass Blind Plate Valve

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Abstract

To address the issues of conventional easy-to-drill blind plates, such as failure to achieve internal blowout prevention function, high construction costs, and risks of pipe string wear, a drill-free glass blind valve was developed in this study through an innovative design of the glass rupture disk structure and multiple fragmentation mechanisms, such as pressure-induced fragmentation, shear pin-controlled impact fragmentation, and external tool piercing and fragmentation, realizing the integration of internal blowout prevention function and convenient disposal. Based on the broken principle of glass plate, the structural design of the blind plate valve was conducted, and the key functions and parameters of the blind plate valve were verified through laboratory test. Meanwhile, field applications show that the drill-free glass blind plate valve can effectively solve the problem of needing additional time to drill through the blind plate in the later stage, and can effectively adapt to the operation requirements of easy-to-blowout and easy-to-leak reservoirs in the Tarim Oilfield, significantly reducing the probability of pipe string wear during the construction process. This study provides reliable technical support for the safe and efficient operation of high-risk reservoirs.

Keywords

Easy-to-Drill Blind Plate, Drill-Free Glass Blind Plate Valve, Structural Design, Experimental Verification, Field Application

1. Introduction

The fractured-vuggy carbonate reservoirs in the Tarim Basin, Northwest China, exhibit distinct characteristics of being easy-to-blowout, easy-to-leak, and high in hydrogen sulfide content [1]-[4]. However, the existing completion strings still have obvious functional defects and fail to achieve an effective internal blowout prevention function. The main reasons for this failure are as follows: The blowout prevention and sealing structures of the existing completion strings mostly adopt conventional rubber seals. Under the high-pressure environment (often reaching 50 - 100 MPa) and frequently fluctuating pressure conditions of the reservoir, such seals are prone to rapid elastic fatigue, leading to a decrease in the fitting accuracy of the sealing surface; meanwhile, the carbonate solid particles carried in the reservoir fluid will cause continuous wear on the surface of the seals, damaging the integrity of the sealing interface. This makes it difficult to form an effective plugging for the blowout prevention channel, and ultimately results in the failure of the internal blowout prevention function. This defect causes the tubing and casing to be in a connected state during tripping operations, making high-pressure formation fluids highly prone to channeling through the annulus. Thereby, it triggers severe accidents such as blowouts and hydrogen sulfide leaks, causing oil testing operations to face significant well control safety risks and seriously restricting the safety and efficiency of operations [5]-[7]. Meanwhile, the supporting string assembly of "drill pipes + telescopic subs + permanent hangers + casings + easy-to-drill blind plates + screens" adopted in the traditional liner completion technology also has many problems [8]-[10]. Among them, although the easy-to-drill blind plates can temporarily isolate formations from wellbores at the initial stage of operations, they require additional significant time to drill through in the later stage. This not only increases construction costs, but also the rigid contact between drilling tools and blind plates during the drilling process is highly likely to cause pipe string wear, affecting the service life and sealing performance of the pipe strings. More seriously, residual metal debris may also be generated during the drilling process. If these debris are not cleared in a timely manner, they may block wellbore channels and damage downhole tools, thereby posing hidden risks for subsequent operations [11]-[13].

Regarding the issues currently faced by blind plates, relevant scholars have already conducted extensive research on this issue. Yang Lin *et al.* [14] analyzed the sealing failure of quick-opening blind plates. Through on-site mapping, inspection, and analysis of the sealing principle, they identified that the corrosion in the hydrogen sulfide environment leading to changes in the sealing structure is the fundamental cause of the sealing failure. Wang Limei [15] analyzed the faults of lock ring-type quick-opening blind plates, including difficulty in opening and leakage after resetting, and revealed that the faults were caused by issues such as the absence of dust-proof sealing rings and impurities/paint on the lock rings. Zhu Xiaodan *et al.* [16] conducted electrical stress measurement experiments on pressure ring-type quick-opening blind plates, compared the results with finite element analysis (FEA) outcomes to verify the model accuracy, used the stress classification method and elastic-plastic analysis method for strength check, and optimized the head thickness of the quick-opening blind plates. They revealed that the quick-opening blind plates had good sealing performance, the strength of each component met requirements, and the optimized head could also meet strength requirements, which can provide a reference for the localized design of large-scale high-pressure quick-opening blind plates.

Therefore, based on the fragmentation principle of glass rupture disks, and integrating structural design, experimental verification, and field application, this paper carried out research on the performance optimization and engineering application technology of the Drill-Free Glass Blind Plate Valve. The Drill-Free Glass Blind Plate Valve is designed to replace conventional easy-to-drill blind plates. As a key internal blowout prevention tool, it can effectively block the communication channel between tubing and casing, cut off the channeling paths of high-pressure fluids and hydrogen sulfide gas at the source of operations, and thus comprehensively control overflow phenomena and mud loss during the oil testing and completion process. The Drill-Free Glass Blind Plate Valve not only eliminates the equipment investment and time costs required for drilling and grinding operations, but also fundamentally avoids risks such as pipe string wear and residual metal debris that may occur during the drilling and grinding process. Finally, it achieves a significant improvement in the well-controlled safety factor and an effective reduction in comprehensive operation costs.

2. Development of the Drill-Free Glass Blind Plate Valve

2.1. Structural Composition

The Drill-Free Glass Blind Plate Valve is mainly composed of upper adapters, outer cylinders, impact sliding sleeves, shear pins, glass rupture disks, buffer pads, lower adapters, and other components, as shown in Figure 1. Among them, glass rupture disks are the core functional components. Made of special glass material, they possess high strength, high toughness, and controllable fragmentation characteristics.

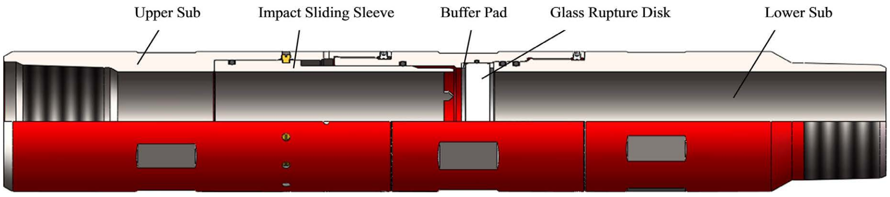

Figure 1. Structural schematic diagram of the drill-free glass blind plate valve.

Existing drill-free glass blind plate valves come in two specifications: 146 mm and 152 mm, with specific parameters as shown in Table 1.

2.2. Working Principle

The Drill-Free Glass Blind Plate Valve integrates sealing components and a controllable breaking mechanism to achieve three core functions: 1) It acts as an

Table 1. Drill-Free glass blind plate valve specification.

Specification	ID (mm)	Working Pressure Difference (MPa)	Internal Pressure Strength (MPa)	Extrusion Strength (MPa)	Tensile Strength (kN)	Plunger Breaking Pressure (MPa)	Pressure Breaking Pressure (MPa)
146 mm	108	70	75.5	73	1960	4.5 MPa	50 - 63
152 mm	108	70	91	87	1745	4.5 MPa	50 - 63

internal blowout prevention tool to block the communication between the oil tube and casing and maintain a stable wellbore liquid level; 2) It withstands high pressure to meet the pressure requirements for setting and suspending packers; 3) It realizes controllable breaking, which eliminates the drilling and grinding process required for traditional blind plates. Moreover, the broken particles are small enough to be returned with well washing fluid, enabling clean well completion.

Among these, the high-pressure glass rupture disk is shown in Figure 2, and the physical performance indicators of the glass rupture disk are listed in Table 2.

Figure 2. High-pressure glass rupture disk schematic diagram.

Table 2. Table of physical performance indicators for glass rupture disk.

Serial No.	Performance Indicator	Value	Serial No.	Performance Indicator	Value
1	Density	3.5 g/cm^3	8	Softening Point	788˚C
2	Hardness	7.5 Mohs	9	Maximum Service Temperature	300˚C
3	Young's Modulus	8380 N/mm^2	10	Thermal Shock	≤230˚C
4	Burst Bending Strength	560 MPa	11	Burst Pressure	15~70 MPa, customizable
5	Poisson's Ratio	0.27	12	Water Resistance	ISO719 HGB 1
6	Coefficient of Thermal Expansion (20˚C - 350˚C)	68 × 10^{-7}/K	13	Acid Resistance	ISO195 HGB A1
7	Refractive Index	1.6722	14	Alkali Resistance	ISO695 HGB A1

There are three breaking methods for the glass rupture disk of the drill-free glass blind plate valve as follows:

1) Pressure-induced fragmentation: Controllable pressure threshold is achieved by pre-calibrating the rated fragmentation pressure of the glass rupture disks. When the tubing pressure naturally rises to this rated value, the rupture disks burst as the internal and external stress difference reaches the preset fracture critical point. Flow interruption is triggered only when the pressure meets the set conditions, avoiding false or delayed flow interruption caused by pressure fluctuations and ensuring the flow interruption timing is accurately matched with the pressure working conditions;

2) Shear pin-controlled impact fragmentation: Taking the preset bearing strength of shear pins as the control benchmark, controllable pressure difference triggering is realized. When the tubing-casing pressure difference exceeds the rated shear strength of the shear pins, the shear pins break precisely, and only then does the hydraulic pressure push the impact sliding sleeve to strike the rupture disks—through the preset mechanical parameters of the shear pins, the trigger conditions for the impact action are defined, preventing false impacts caused by minor pressure difference fluctuations and ensuring flow interruption is executed in an orderly manner only when the pressure difference exceeds the standard;

3) External tool piercing and fragmentation: Active on-demand controllability is achieved by manually controlling the running timing and acting force of external tools. The flow interruption action is completely actively triggered by operators based on construction progress; the glass rupture disks are fragmented precisely when direct mechanical external force from the tools acts on them, without being affected by fluctuations in operating conditions such as wellbore pressure and pressure difference, thus realizing active control of “on-demand flow interruption”.

The rupture disks burst into fine particles in a fragmented manner.

3. Performance Evaluation and Testing of the Drill-Free Glass Blind Plate Valve

3.1. Test Purpose and Scheme

To ensure that the Drill-Free Glass Blind Plate Valve functions stably and reliably under complex well conditions, it is necessary to conduct comprehensive verification of its comprehensive performance in response to the actual application requirements of this tool in harsh environments, such as high temperature, high pressure, hydrogen sulfide-containing conditions, and easy-to-blowout and easy-to-leak fractured-vuggy reservoirs.

Therefore, this study referred to the API SPEC 19V-2019 standard and formulated a comprehensive performance evaluation test plan for the Drill-Free Glass Blind Plate Valve, as shown in Table 3. The tests mainly include low-temperature isolation and sealing test, high-temperature isolation and sealing test, combined load test, internal pressure withstand test, external extrusion withstand test, tension and compression withstand test, upper forced opening glass fragmentation test, pressure-induced fragmentation test, and striker pin fragmentation test. Through the above comprehensive tests, the reliability of the Drill-Free Glass Blind Plate Valve under complex well conditions can be systematically evaluated, providing a scientific basis for its field application.

Table 3. Table of test items.

Serial No.	Test Item	Test Condition	
		Temperature	Pressure
1	Low-temperature Isolation and Sealing Test	≤30˚C	maximum 35 MPa for each of upper and lower cavities
2	High-temperature Isolation and Sealing Test	≥170˚C	maximum 35 MPa for each of upper and lower cavities
3	Combined Load Test	/	Central cavity > 35 MPa, tension/compression ≥ 588 kN;
		/	External pressure > 35 MPa, tension/compression ≥ 588 kN
4	Internal Pressure Withstand Test	≥170˚C	internal pressure up to ≥76.8 MPa
		/	Ultimate pressure or press until the body is damaged
5	External Extrusion Withstand Test	≥170˚C	external pressure > 92.8 MPa
		/	External ultimate pressure or press until the body is damaged
6	Tension and Compression Withstand Test	≥170˚C	axial tension force ≥ 1445 kN
		≥170˚C	axial compression force ≥ 1445 kN
7	Upper Forced Opening Glass Fragmentation Test	≥170˚C	connect forced opening tool to apply axial compression force until the valve plate is fragmented
8	Pressure-induced Fragmentation Test	≥170˚C	pressurize central cavity to fragment glass
		≥170˚C	pressurize lower cavity to fragment glass
		≥90˚C	pressurize central cavity to fragment glass
		≥90˚C	pressurize lower cavity to fragment glass
9	Striker Pin Fragmentation Test	≥90˚C	pressurize central cavity of the tool to impact and fragment glass
		≥170˚C	pressurize central cavity of the tool to impact and fragment glass

3.2. Test Equipment

The test device is mainly composed of a Test Wellbore System, an Ultra-High Pressure Liquid Test System, a Temperature Cycling System, and a Force Loading Test System. The Test Wellbore System is mainly composed of a test wellbore, liner assemblies, heating jackets, thermal insulation jackets, and wellbore accessories, which can provide setting, unsetting, pressure-bearing, and sealing test environments for downhole tools; The Ultra-High Pressure Liquid Test System can provide a high-pressure source exceeding 100 MPa, and can realize pressure control for the upper cavity, lower cavity, and central tube of the tools in the test wellbore; The Temperature Cycling System can provide a high-temperature test environment exceeding 170˚C for downhole tools, which can meet the test requirements. The Force Loading Test System realizes connection with the wellbore, performs tension, compression, and rotational loading on the test tools inside the wellbore, and can meet the test conditions of applying over 1445 kN.

The Field Test Device is shown in **Figure 3**.

Figure 3. Field device diagram.

3.3. Main Test Results

1) Low-Temperature Isolation and Sealing Test

Under the condition of temperature ≤ 30˚C, the upper and lower cavities bore a maximum pressure of 35 MPa respectively to conduct a sealing test. Test results show that under a pressure load of 35 MPa, the pressure drops of the tool's internal pressure and external pressure were both less than 1% within 15 minutes, and the sealing performance is qualified.

2) High-Temperature Isolation and Sealing Test

Under the condition of temperature ≥ 170˚C, the upper and lower cavities bore a maximum pressure of 35 MPa respectively to conduct a sealing test. Test results show that under a pressure load of 35 MPa, the pressure drops of the tool's internal pressure and external pressure were both less than 1% within 15 minutes, and the sealing performance is qualified.

3) Combined Load Test

Under the condition of central cavity pressure > 35 MPa, tension/compression load ≥ 588 kN was applied simultaneously; the same test was conducted under the condition of external pressure > 35 MPa. The test is as shown in **Figure 4**. Test results show that under the combined load condition of 35 MPa and 588 kN, the pressure drops of the tool's internal pressure and external pressure were both less than 1 % within 15 minutes, the sealing performance is qualified, and the tool has no deformation.

4) Internal Pressure Withstand Test

Under the conditions of temperature ≥ 170˚C and internal pressure > 76.8 MPa, the test results show that when pressurized to 77.5 MPa, the tool had no deformation; in addition, an Internal Ultimate Pressure Test was conducted, and the test results show that the pressurized ultimate pressure of 101 MPa exceeded the pressure-bearing ultimate pressure of the joint (96.3 MPa), the body is undamaged, and the pressure drop is qualified.

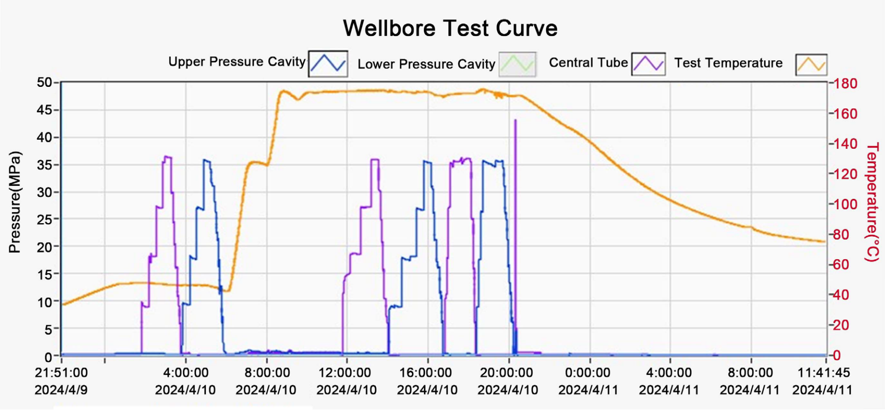

Figure 4. Test pressure curve.

5) External Extrusion Withstand Test

Under the conditions of temperature ≥ 170˚C and external pressure > 92.8 MPa, the test results show that when pressurized to 93.6 MPa, the tool had no deformation; in addition, an External Ultimate Pressure Test was conducted, and the test results show that the pressurized ultimate pressure of 100 MPa exceeded the pressure-bearing ultimate pressure of the joint (96.3 MPa), the body is undamaged, and the pressure drop is qualified.

6) Tension and Compression Withstand Test

Under the conditions of temperature ≥ 170˚C and axial tensile force ≥ 1445 kN, the test results show that when the tensile load reached 1460.1 kN, the tool had no deformation; under the same temperature condition, with axial compressive force ≥ 1445 kN, the test results show that when the compressive load reached 1482.2 kN, the tool had no deformation.

7) Upper Forced Opening Glass Fragmentation Test

At a temperature ≥ 170˚C, connected the forced opening tool and applied axial compressive force until the valve plate was crushed. The test is as shown in **Figure 5**. Test results show that the valve plate was crushed when an axial compressive force of 191.9 kN was applied.

8) Pressure-Induced Fragmentation Test

Tests are conducted for the following working conditions respectively: 1) Under the condition of temperature ≥ 170˚C, the central cavity was pressurized to 48 MPa, and the glass rupture disk was crushed; 2) Under the condition of temperature ≥ 170˚C, the lower part was pressurized to 55.8 MPa, and the glass rupture disk was crushed; 3) Under the condition of temperature ≥ 90˚C, the central cavity was pressurized to 65.2 MPa, and the glass rupture disk was crushed; 4) Under the condition of temperature ≥ 90˚C, the lower part was pressurized to 70.1 MPa, and the glass rupture disk was crushed; The test verifies the stability of the pressure-building crushing mechanism under high-temperature and medium-temperature environments.

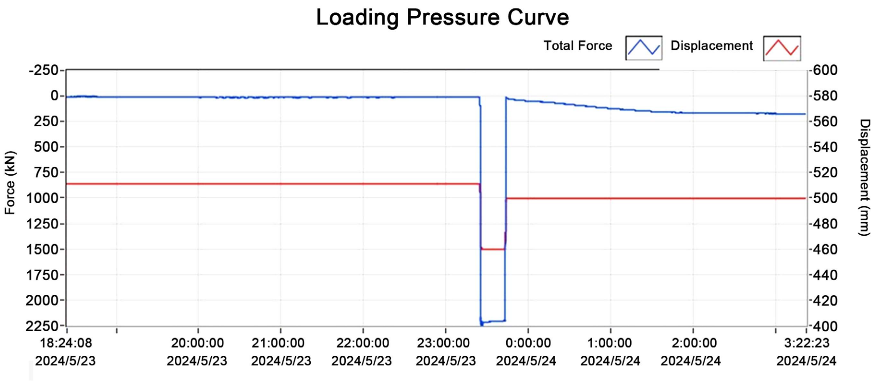

Figure 5. Glass forced opening crushing test curve.

9) Striker Pin Fragmentation Test

For the impact sleeve crushing mechanism controlled by shear pins, at 90˚C, the central cavity was pressurized to 37.2 MPa, and the glass rupture disk was crushed; at 170˚C, it was pressurized to 37.3 MPa and crushed. This is consistent with the design value of 36 MPa corresponding to a minimum of 8 shear pins of 146 mm specification, verifying the controllability of the crushing pressure of the firing pin under different temperatures.

4. Field Application

4.1. Application Overview

Currently, drill-free glass blind plate valves of 152 mm and 146 mm specifications have been cumulatively applied in 9 well times in Tarim Oilfield. Among them, 7 well times adopted the pressure-building crushing method and 2 well times adopted the mechanical piercing crushing method, as shown in Table 4. All successfully achieved crushing and wellbore communication, with an operation success rate of 100%.

Table 4. Field application.

Well No.	OD (mm)	Depth (m)	Temperature (˚C)	String Configuration	Fracturing Method	Actual Crushing Load
G1	152	7752	157.37	Hanger + Blind Plate	Pressure	43.8 MPa
G2	146	6662.3	139.24	Liner Hanger + Blind Plate	Pressure	40 MPa
G3	146	6682.8	132.97	Liner Hanger + Blind Plate	Pressure	53 MPa
G4	146	7491	122.85	Liner Hanger + Blind Plate	Pressure	52 MPa
G5	152	7473	/	Hanger + Blind Plate	Pressure	57.15 MPa
G6	146	6960.9	/	Liner Hanger + Blind Plate	Pressure	57.5 MPa
G7	146	/	/	/	Pressure	53 MPa
G8	146	/	/	/	Mechanical	240 kN
G9	146	/	/	/	Mechanical	110 kN

4.2. Typical Case

G1 Well is a key development well deployed in the northern part of the Tarim Basin in China. The well adopts the string combination scheme of “7-5/8" 337 W permanent suspension packer + 5" PSVA drill-free glass blind plate valve”. Among them, the drill-free glass blind plate valve is of 152 mm specification, with a setting depth of 7551.98 m, and was equipped with 10 shear pins. This ensures that it not only meets the setting requirements of the suspension packer, but also can be quickly crushed through a controllable method.

The construction team ran in the string as per the scheme: First, the 7-5/8" 337 W hanger was set at a depth of 7703.54 m; after passing the suspension and sealing tests, it was confirmed that the lower 5" PSVA drill-free glass blind plate valve had intact sealing performance. Subsequently, the glass rupture disc crushing operation was carried out by continuously applying positive pressure inside the tubing. When the pressure rose to 43.8 MPa, the glass rupture disc burst instantly. After crushing, the proportion of particles with a size ≤ 5 mm × 5 mm × 5 mm exceeded 90 %, which could be completely returned through subsequent well washing. The on-site test is shown in **Figure 6**.

Figure 6. Photographs of drill-free glass blind plate valve running into the well and pressure-induced crushing.

5. Conclusions

A drill-free glass blind plate valve has been developed in this paper by integrating key components such as the upper joint, outer cylinder, impact sleeve, shear pins, glass rupture disc, and buffer pad through structural design. It targetedly solves the problems of fractured-vuggy carbonate reservoirs in Tarim Oilfield, such as proneness to blowout and leakage and high sulfur content, as well as the issues of existing completion strings lacking internal blowout prevention function, and traditional blind plates requiring additional drilling and grinding, which leads to high costs and high risks. This structural design achieves the synergy between internal blowout prevention sealing and controllable crushing, and can support completion and well testing operations in ultra-deep, ultra-high-pressure sulfur-containing oil and gas wells.

1) Achieve reliable internal blowout prevention and safe isolation. Through the

sealing design of components such as the upper joint, outer cylinder, and glass rupture disc, the valve can withstand pressure above 35 MPa in both low and high temperature environments. It blocks the communication between the tubing and casing during tripping operations, maintains a stable liquid level in the tubing bore, solves the problem that existing strings lack blowout prevention capability, and significantly reduces the blowout risk in high-sulfur reservoirs.

2) Achieve multi-method controllable crushing and clean completion. It integrates three mechanisms: pressure-building crushing, shear pin impact crushing, and external tool piercing crushing. After the glass rupture disc is crushed, the proportion of particles with a size ≤ 5 mm × 5 mm × 5 mm exceeds 90%, which can be completely returned through well washing. This eliminates the 3 - 4 days drilling and grinding process required for traditional blind plates, reduces the risk of string wear, and meets the requirements of clean completion.

3) On-site application shows that the valve can effectively adapt to the operation requirements of reservoirs prone to blowout and leakage in Tarim Oilfield. It significantly improves the efficiency of well testing and completion, reduces well control risks, and provides important technical support for the safe development of ultra-deep, high-temperature, high-pressure sulfur-containing oil and gas wells. In the future, further optimization can be made to the glass material formula and structural design to expand its application range under higher temperature and pressure conditions. Meanwhile, intelligent technologies can be integrated to realize real-time monitoring and control of the crushing process.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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