# Application of Fracturing Technology for Temporary Blockage and Turning of Rope Knots in Complex Fault Block Oilfield

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**Abstract.** The main characteristics of reservoirs in complex fault block oil fields are thin inter-bedded development, small oil layer thickness, and high mud content in the inter-layer. To improve the utilization degree of vertical oil layers, it is necessary to use inter-layer temporary blockage and directional fracturing technology during fracturing construction. Fushan Oilfield is a complex fault block oilfield. Before 2021, soluble balls and particle temporary blockage agents were mainly used in Fushan Oilfield to achieve inter-layer temporary blockage. However, during on-site implementation, there were issues with unclear temporary blockage pressure response and even particle temporary blockage agents blocking the plunger valve of fracturing pump trucks.In the past two years, through the improvement of temporary blockage materials and processes, a new type of knot temporary blockage ball has been used to replace the previous soluble balls and particle temporary blockage agents. At the same time, thin inter-layer perforation optimization, analysis of the erosion law of sand carrying fluid on the perforation hole, and research on the matching of the diameter and quantity of knot temporary blockage balls with the perforation hole have been carried out indoors. The fracturing technology technology for temporary blockage and turning of knots that adapts to reservoir characteristics has been applied in Fushan Oilfield and has achieved good temporary blockage and turning effects as well as increased production.

**Keywords:** thin inter-bedded layers; fracturing; temporary blockage and turning; temporary blockage agent; rope knot temporary blockage ball; Sealing performance; Fushan Oilfield

## 1 Introduction

Fushan Oilfield is a complex fault block condensate oil and gas reservoir, with the main oil and gas bearing layers being the Lower Tertiary Liushagang Formation and Weizhou Formation clastic rock reservoirs. The reservoir is mainly composed of medium porosity and low permeability, with significant vertical differences in reservoir properties and poor matching of porosity and permeability. Some reservoirs are dense, with


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porosity ranging from 8.9% to 13.6% and permeability ranging from 0.03 to 9.4 mD. The average effective reservoir porosity is 10.3% and the average permeability is 1.1 mD[1]. The reservoir exhibits the characteristics of thin inter-bedded sand and mudstone in the vertical direction, with the thickness of oil and gas reservoir is 0.7-5.8m and the average layer thickness of 1.7m. Moreover, the vertical span of the oil and gas reservoir is large, with poor continuity and strong heterogeneity [2-3].

Fushan Oilfield has been implementing fracturing to increase production and efficiency since 1999. Until 2021, the main fracturing methods used for thin inter-bedded layers were pad fluid injection ball layered fracturing technology[4], and composite particle temporary blockage agent temporary blockage and turning fracturing technology[5-8]. In practical application on site, the differences in reservoir conditions, sealing material properties, and temporary blockage steering process design can affect the effectiveness of temporary blockage steering, often lead to problems, such as unclear temporary blockage pressure response, particle temporary blockage agents affecting the calibration of fracturing pump trucks, and even blocking the plunger valve of fracturing pump trucks[9-11]. To further improve the effect of inter-layer temporary blockage and turning, a new type of rope knot temporary blockage and turning fracturing technology has been explored and studied since 2022, Further improvements have been made in the materials and structure of temporary blockage agents, sealing effectiveness, sealing controllability, hole abrasion, etc. Experimental applications have been carried out in oilfield sites.

## 2 Mechanism of Temporary Blockage and Turning of Rope Knots

A new type of rope knot temporary blockage ball replaces the previous soluble ball and particle temporary blockage agent, which uses high-strength, flexible and biodegradable fiber materials to weave a core containing knot shaped and scattered tail wings, and wraps a layer of soluble material around the periphery to form a ball. During on-site application, specific equipment such as bypass and ball throwers are used to pump fluid into the well-bore. During the pumping process, the outer packaging material ruptures and dissolves, exposing the knot like core and entering the perforation channel with the fluid. Through the joint action of the junction structure and the scattered tail wing of knots, the perforation is sealed, thereby achieving temporary blockage and diversion. After construction, the knots degrade within the required specified time, and the perforation hole flow channel is restored.

## 3 Characteristics of Rope Knot Temporary Blockage Ball

The core of the temporary knot ball is mainly made of high-strength, flexible, and biodegradable fiber materials, which are woven into a "knot" shape with a main body of knots and a loose end through knotting and other methods, with a length of 5-10cm.

The size of the knot can be adjusted according to the size of the perforation hole, commonly used being 15mm, 18mm, 20mm, 22mm, and 25mm.

The shell of the temporary blockage ball in the knot is mainly made of soluble material paraffin, which is used to wrap the knot and make it into a ball shape. During the injection process, it can quickly break and dissolve to release the knot core, making it easy to pump. The specific physical object is shown in Figure 1.

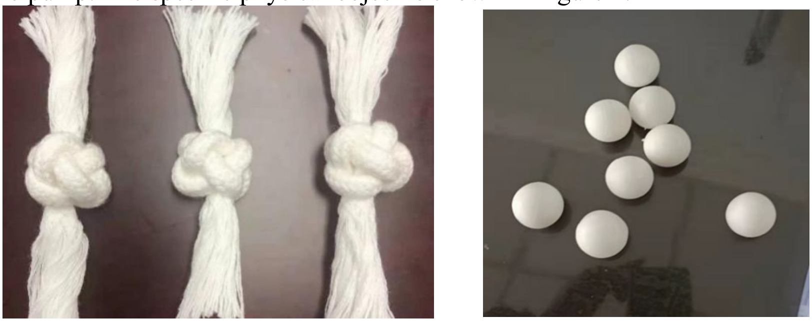

**Fig. 1.** Core and shell of the rope knot temporary blockage ball.

The main advantages of rope knot temporary blockage balls are adaptive and efficient temporary blockage, high sealing reliability, high sealing pressure, low usage, simple use, controllable degradation time, no pollution to the formation, and environmentally friendly

The "tassel shaped" two wing structure can achieve the suspension and rotation of knots in the well-bore, making it easier to seal perforations with different phase angles.It has a higher sealing efficiency than conventional soluble balls, and the number of usage can be reduced by more than 20%, making it very cost-effective.

(2) The knot structure has better adhesion and can be embedded into different shaped perforations, especially irregular perforations worn by support agent. And the more pressure is applied, the more solid it becomes, which can solve the problem of poor sealing and easy detachment of conventional soluble balls.

(3) Based on the number of perforation holes and the size of perforation wear, the number and size of temporary blockage balls can be optimized to achieve precise sealing and improve sealing reliability.

(4)The core of the rope knot temporary blockage ball is mainly made of high-strength, flexible, and biodegradable fiber materials. According to the formation temperature, the degradation time can be controlled, generally 24-168 hours, and the degradation rate can reach over 98%. It is pollution-free to the formation and environmentally friendly.

(5)The rope knot temporary blockage technology is widely applicable and not limited by reservoir characteristics. It only needs to be scientifically optimized in high-pressure well fracturing to avoid excessive pressure increase beyond the wellhead pressure limit after the rope knot temporary blockage ball is inserted.

# 4 Fracturing Technology for Temporary Blockage and Turning of Rope Knots

A successful temporary blockage and fracturing construction requires not only high-performance temporary blockage agents, but also a scientifically reasonable design of the temporary blockage and fracturing process.

## 4.1 Design Of Perforation Parameters for Thin Inter-Layers

The key to thin inter-layered fracturing is to achieve balanced expansion and extension of each vertical small layer. By reducing the number of single shower holes in flow limiting fracturing, it is beneficial to improve the uniformity of each cluster transformation and reduce the difference in liquid inflow of each cluster. However, it is prone to generate higher hole friction and ground construction pressure. Taking into account the inter layer stress differences (2.1-4.4MPa) in the main oil and gas reservoirs of Fushan Oilfield, To ensure that all perforation clusters can enter and expand, the effective well-bore friction is generally required to be greater than 5MPa (calculation of hole friction can be found in formula 1). According to the relationship between the number of perforations and friction (see Figure 2), to ensure better flow limiting effect, the number of perforations in each section is 36-48. Therefore, Wells with a perforation layer thickness of ≥ 3m have a perforation density of 12 holes/m and a phase angle of 60°, and wells with a perforation layer thickness of<3m have a perforation density of 16 holes/m and a phase angle of 60 °.

$$P_{pf}=22.4Q^2\times\rho/(N^2\times d\times C) \tag{1}$$

Among them: $P_{pf}$ - orifice friction, MPa;
Q - displacement, $m^3$/min;
ρ - fluid density, g/$cm^3$;
N-total number of perforations, dimensionless;
d-hole diameter, cm;
C-hole flow coefficient, dimensionless

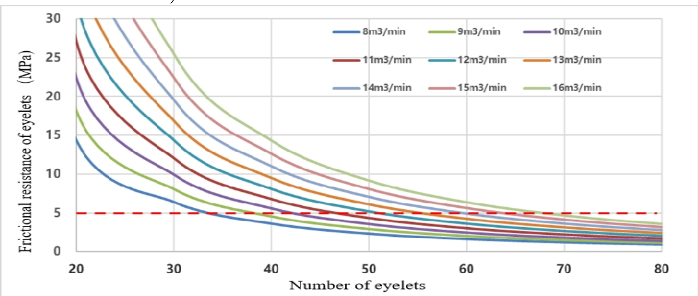


**Fig. 2.** Diagram of the relationship between the number of holes and the friction resistance of holes (5-1/2″casing, 10mm diameter).

### 4.2 Design of the Dosage of Rope Knot Temporary Blockage Balls

The design steps are as follows: firstly, analyze the stress profile of the fracturing target layer based on logging data; secondly, predict the sequence of fracturing opening for each cluster based on the physical properties and stress differences of each perforation cluster in the target layer; finally, optimize the amount of knot temporary blockage balls based on the number of perforation holes in each cluster. To ensure the temporary blockage effect, the amount of rope knot temporary blockage balls is generally designed to be 1.0-1.5 times the number of holes that need to be blocked [12-13].

### 4.3 Design of the Size of Rope Knot Temporary Blockage Balls

Through other oilfield field experiments and down-hole television monitoring data, it has been found that the prop-pant has a strong abrasive effect on the perforation hole during sand addition, which can lead to an increase in the hole size, with the average aperture increasing from 10.5mm to 15.8mm [14]. To ensure the success rate of temporary ball blockage with knots, it is necessary to analyze the erosion law of sand carrying fluid on the hole, as well as to study the matching of sand adding scale with the size of temporary ball blockage with knots and hole size [15-16]. Considering that the commonly used perforation charges in Fushan Oilfield are the DK34RDX21-2 and DP43RDX45-2 types, with perforation hole diameters of 11.7mm and 12.5mm respectively. Based on an average construction displacement of 10m3/min, an average sand concentration of 320kg/$m^3$, and an average erosion time of 3600s, the estimated perforation hole diameter after erosion is approximately 18.36-23.02mm (calculation of erosion hole diameter can be found in formula 2). Therefore, three sizes (15mm, 20mm, 25mm) of composite rope knot temporary blockage balls are actually used on site. The proportion of temporary blockage balls with three sizes is mainly determined by the amount of sand passing before temporary blockage. If the amount of sand passing before temporary blockage is small (<30$m^3$), the proportion of temporary blockage balls with small-sized knots is correspondingly increased (2:2:1). If the amount of sand passing before temporary blockage is large (>30$m^3$), the proportion of large-sized knot temporary blockage balls should be increased accordingly (1:1:2), and the size and placement ratio of temporary blockage balls can also be adjusted on site based on the actual pressure response situation.

$$\Phi = 5.49 \times 10^{-7} \times C \times \mu^{1.71} \times t/\rho \quad (2)$$

Among them: $\Phi$ - erosion hole diameter, mm;
C - sand concentration, kg/$m^3$;
μ - liquid flow rate, m/s
t - erosion time, s;
ρ - density of casing steel, kg/$m^3$

## 5 Effectiveness of Temporary Blockage and Turning

The most intuitive way to judge the effectiveness of temporary blockage and turning action is through micro-seismic monitoring, fiber optic monitoring, and other means. It is possible to visually observe the opening and extension of cracks before and after temporary blockage. However, due to cost considerations, crack monitoring can't be implemented in every well on site. More wells still need to be judged through wellhead pressure response [17], that is, by judging the pressure difference of temporary blockage and turning, and the fracturing operation pressure difference (see Figure 3).

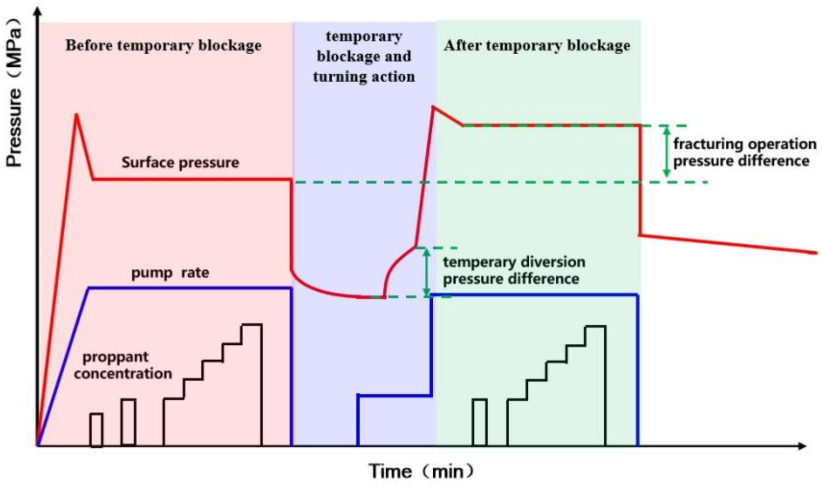


**Fig. 3.** Schematic diagram of temporary blockage diversion to fracturing construction curve.

(1) During the process of pumping rope knot temporary blockage balls in the wellbore, when the temporary blockage balls reach the position of the perforation hole, there will be a significant increase in wellhead pressure. The increase in pressure here is a sign of temporary blockage formation and a necessary condition for achieving temporary blockage and turning.

(2) In the later stage of fracturing construction, the temporary blockage and turning to the two stages before and after construction. At the same construction displacement, the construction pressure increases, and the construction pressure after temporary blockage is higher than the construction pressure before temporary blockage, which is a typical characteristic of long-term effectiveness of temporary blockage.

Therefore, for fracturing wells that have not undergone crack monitoring, on-site personnel can judge the effectiveness of temporary blockage and turning based on two criteria: temporary blockage pressure response and comparison of construction pressure before and after temporary blockage. If both pressures have been significantly increased, it can be determined that the temporary blockage and turning is effective; If only one pressure is increased, it can be judged that the temporary blockage and turning is basically effective; If both pressures are not effectively increased, it can be judged that the temporary blockage and turning is basically ineffective.

# 6 On Site Application

Since 2021, the fracturing technology for temporary blockage and turning of rope knots has been tested and applied on site in Fushan Oilfield. Currently, a total of 17 wells and 27 layers have been implemented (see Table 1), achieving good temporary blockage and turning effects and increasing production. The effective rate of temporary blockage and turning is 82%, with an average daily oil increase of 4.28t/d.

**Table 1.** Statistical table of rope knot temporary blockage and turning to fracturing test well.

| Well number | Fracturing well section (m) | Perforation thickness/number of clusters (m) | Number of holes | Amount of rope knot temporarily blocking the ball | Construction pressure before and after temporary ball blockage in place (MPa) | | | Construction pressure before and after temporary blockage (MPa) | | | Effectiveness of temporary blockage and turning | Daily increase in oil production after compression (t/d) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Before | After | Pressure difference | Before | After | Pressure difference | | |
| H107-93x | 3396.0-3417.0 | 3.9m/6 | 47 | 35 | 32.77 | 36.57 | 3.80 | 38.78 | 45.84 | 7.06 | Effective | 5.80 |
| | 3362.0-3382.8 | 5.0m/6 | 60 | 45 | 29.77 | 41.76 | 11.99 | 40.74 | 50.56 | 9.82 | Effective | |
| | 3335.0-3347.7 | 3.5m/5 | 42 | 32 | 31.95 | 37.42 | 5.47 | 41.23 | 49.29 | 8.06 | Effective | |
| H107-96x | 3449.5-3472.1 | 4.5m/8 | 54 | 43 | 35.03 | 37.01 | 1.98 | 36.81 | 40.05 | 3.24 | Basically effective | 4.43 |
| | 3425.0-3441.2 | 4.0m/4 | 48 | 45 | 30.35 | 60.00 | 29.65 | 38.19 | 53.26 | 15.07 | Basically effective | |
| | 3399.3-3418.1 | 4.5m/6 | 54 | 43 | 33.83 | 38.80 | 4.97 | 39.19 | 45.62 | 6.43 | Effective | |
| | 3379.0-3393.6 | 4.5m/5 | 54 | 43 | 36.83 | 40.21 | 3.38 | 41.21 | 49.40 | 8.19 | Effective | |
| H107-97x | 3407.2-3439.0 | 6.0m/7 | 72 | 48 | 33.93 | 37.57 | 3.64 | 40.63 | 45.25 | 4.62 | Effective | 4.05 |
| H107-103x | 3485.9-3518.2 | 4.5m/5 | 54 | 43 | 40.83 | 60.00 | 19.17 | 41.10 | 53.26 | 12.16 | Basically effective | 3.61 |
| | 3460.2-3478.2 | 5.5m/6 | 66 | 40 | 34.32 | 37.61 | 3.29 | 43.19 | 48.84 | 5.65 | Effective | |
| H107-108x | 3658.8-3678.9 | 4.5m/5 | 54 | 36 | 33.90 | 37.06 | 3.16 | 37.83 | 48.20 | 10.37 | Effective | 3.93 |
| H107-112x | 3730.3-3761.6 | 4.5m/6 | 54 | 40 | 29.87 | 30.81 | 0.94 | 37.59 | 41.80 | 4.21 | Basically effective | 1.48 |
| H107-64x | 3539.2-3560.1 | 5.8m/9 | 70 | 52 | 31.36 | 34.95 | 3.59 | 35.97 | 41.42 | 5.45 | Effective | 4.51 |
| | 3490.0-3505.0 | 4.5m/4 | 54 | 54 | 36.05 | 39.15 | 3.10 | 39.87 | 47.30 | 7.43 | Effective | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H107-94x | 3345.2-3368.5 | 5.0m/6 | 60 | 72 | 35.59 | 50.41 | 14.82 | 40.16 | 48.75 | 8.59 | Effective | 5.08 |
| | 3305.5-3333.3 | 6.5m/7 | 78 | 56 | 31.73 | 36.09 | 4.36 | 36.15 | 40.83 | 4.68 | Effective | |
| H107-102x | 3475.6-3490.5 | 5.0m/5 | 60 | 48 | 39.62 | 60.00 | 20.38 | / | / | / | Ineffective | 1.61 |
| H107-106x | 3631.0-3655.7 | 4.0m/6 | 48 | 45 | 33.78 | 36.96 | 3.18 | 40.73 | 52.27 | 11.54 | Effective | 2.91 |
| Y27x | 4635.3-4668.2 | 7.0m/6 | 84 | 63 | 62.6 | 62.91 | 0.31 | 68.64 | 70.57 | 1.93 | Ineffective | 0.50 |
| H30Ax | 3442.4m-3470.4 | 7.0m/5 | 84 | 108 | 40.89 | 60.00 | 19.11 | 41.21 | 56.18 | 14.97 | Basically effective | 3.80 |
| C17x | 2912.6-2944.6 | 6.0m/5 | 72 | 54 | 27.35 | 30.56 | 3.21 | 31.12 | 34.66 | 3.54 | Effective | 7.60 |
| H140x | 3660.8-3697.6 | 8.1m/5 | 130 | 96 | 43.24 | 47.21 | 3.97 | 44.16 | 48.52 | 4.36 | Effective | 16.10 |
| H7-11x | 4125.6-4145.0 | 5.7m/4 | 68 | 51 | 49.70 | 50.50 | 0.80 | 54.12 | 58.42 | 4.30 | Ineffective | 1.32 |
| | 4090.5-4113.5 | 7.0m/4 | 84 | 63 | 42.86 | 44.13 | 1.27 | 45.58 | 48.69 | 3.11 | Basically effective | |
| | 4060.4-4079.6 | 7.0m/4 | 84 | 63 | 46.58 | 47.03 | 0.45 | 50.07 | 52.67 | 2.60 | Ineffective | |
| H139x | 2815.0-2840.0 | 6.8m/7 | 108 | 85 | 26.97 | 30.57 | 3.60 | 28.77 | 33.13 | 4.36 | Effective | 5.90 |
| HD15x | 3403.6-3417.2 | 4.6m/4 | 74 | 37 | 28.53 | 29.83 | 1.30 | 37.88 | 40.38 | 2.5 | Ineffective | 0.1 |

Due to fiber optic monitoring during the fracturing of H107-93x well, this well is used as a typical well for explanation. H107-93x well fracturing section 3335.0-3347.7m, perforation of 3.5m/5 clusters, perforation density of 12 holes/m, phase angle of 60°, perforation aperture of 11.7mm. The cumulative fracturing fluid used was 535m$^3$, with a cumulative sand addition of 32.5m$^3$, a construction displacement of 9.2-9.5m$^3$/min, and a construction pressure of 28.7-51.2MPa. After adding 20m$^3$ of sand in the first stage, 32 rope knot temporary blockage balls were added. From the fracturing construction curve, it can be seen that after the rope knot temporary blockage balls were in place, the wellhead construction pressure increased from 31.95MPa to 37.42MPa, and the pressure increased by 5.47MPa. The construction pressure before temporary blockage also increased from 41.23MPa to 49.29MPa, and the pressure increased by 8.06MPa. The pressure response was obvious, proving that a good temporary blockage and turning effect has been achieved, and the well has been produced for 180 days after being pressurized. The average daily oil production is 5.8t/d, with a maximum daily oil production of 11.5t/d and a cumulative oil production of 1044 tons, achieving a good increase in production.

The fiber optic monitoring results also intuitively demonstrate a good temporary blockage and turning effect. The main principle is to use the DAS distributed acoustic fiber optic sensing system to identify the inflow situation of different perforation clusters. Before the temporary blockage, the sand injection response in clusters 1, 2, and 5 was strong. After the temporary blockage, the injection response in clusters 3 and 4 was opened, effectively achieving inter cluster turning. Relatively speaking, the overall injection response in cluster 4 was weak, and the transformation effect in clusters 1, 2, 3, and 5 was good.

## 7 Conclusion

The following conclusions have been drawn from the on-site application of the fracturing technology for temporary blockage and turning of rope knots in Fushan Oilfield:

(1) The new type of knot temporary blockage ball has the advantages of adaptive and efficient temporary blockage, high sealing reliability, high sealing pressure, low usage, simple use, full degradation at low temperature, and no pollution. It provides a new means to further improve the inter-layer temporary blockage and turning effect and has good promotion and application value in temporary blockage and turning fracturing.

(2) During the on-site use of knot temporary blockage balls for temporary blockage and turning to fracturing, some wells were also excessively blocked, resulting in overpressure during wellhead construction and even limited subsequent construction displacement. It indicates that there is still room for further in-depth research in terms of optimizing the type, size and quantity of rope knot temporary blockage balls, and timing of knot temporary blockage ball deployment.

(3) In addition to intuitive micro-seismic monitoring, fiber optic monitoring, and other methods, the effectiveness judgment of temporary blockage and turning is also a highly reliable method based on the on-site response to temporary blockage pressure and the comparison of construction pressure before and after temporary blockage.

## Acknowledgments

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