Volume fracturing Of Temporary plugging Agent for Oil Well

Xiaoya Chen¹*, liang Huang², DanZhou² and Yangping Peng²

¹School of Sciences, Southwest Petroleum University, Chengdu 610500, China
²Baikouquan Oil Production Factory, Xinjiang Oilfield Company, Karamay 834011, China

*Corresponding author’s e-mail: danlispwu@sina.com

Abstract. There are many classification methods for temporary plugging volume fracturing. According to different temporary plugging positions and temporary plugging targets, temporary plugging volume fracturing technology can be divided into temporary plugging in fractures and temporary plugging between fractures. According to the number of temporary plugging, it can be divided into one temporary plugging and multi-level temporary plugging. According to the action mode of temporary plugging, it can be divided into physical temporary plugging and chemical temporary plugging. According to the type of temporary plugging agent, it can be divided into plugging balls (plastic balls, rubber balls, nylon balls, wax balls) temporary plugging, fiber temporary plugging, large particle size proppant temporary plugging, etc. In Changqing, Daqing and Xinjiang oilfields in China, temporary plugging agents have been reported to be used for in-fracture diversion fracturing to improve reservoir productivity, and certain effects have been achieved. Compared with conventional staged fracturing, the temporary plugging of the seam to fracturing technology has the following advantages: conventional staged fracturing is difficult to implement, the temporary plugging of the seam to fracturing technology can be used to realize effective layering (segment) reconstruction, general fracturing reconstruction is insufficient, and temporary plugging of the seam to fracturing can be used to improve thereconstruction effect.

1. Introduction
As the production process goes on, the output of unconventional oil wells will always drop sharply. The fluid introduced into the reservoir for stimulation usually adopts the path with the least resistance, so it often enters the area with open flow path. In many cases, this is neither a dessert for fracturing to increase production nor an area where formation damage needs to be eliminated. The success of hydraulic fracturing or acidizing fracturing depends on the maximum contact between fracturing fluid (or acid) and reservoir. In order to achieve this goal, fracturing fluid must be effectively blocked so that the fluid can be suppressed to open the dessert area to be reformed. The traditional staged fracturing technology can achieve this goal, but the construction process is complicated, or the reservoir will be polluted by residual in the reservoir. The temporary plugging agent is used for temporary plugging, and the reservoir fluid can be used for degradation of the temporary plugging agent after the turning fracturing is completed. The technology is simple and the implementation is high.

Temporary plugging volume fracturing is to temporarily plug the previous fracture by delivering high-strength water-soluble temporary plugging agent one or more times, forcing one or more new fractures to open in the section and promoting the expansion of branch fractures, thus obtaining a single well effective reconstruction volume larger than conventional fracturing. Compared with conventional
fracturing, temporary plugging fracturing makes full use of fracturing fluid to naturally optimize reservoir "sweet spot", avoiding artificial determination of "sweet spot" by conventional staged fracturing, and liberating reservoir productivity to the greatest extent.

2. Steering Mechanism and Design Optimization of Temporary Blocking Agent

2.1. Macro-steering Mechanism of Temporary Blocking Agent

The conventional staged fracturing uses mechanical packers to carry out layered reconstruction. However, this technology has complex construction steps and high fracturing construction cost, and the staged fracturing effect is difficult to ensure especially under complex well conditions such as ultra-deep and high temperature and high pressure. As an effective fracturing method, temporary plugging at the seam turns to fracturing technology, which can effectively increase the volume of single well reconstruction.

The mechanism of temporary plugging at the seam turning to fracturing: due to the heterogeneity of the reservoir, the physical properties and fracture pressure of different reservoir sections are different. Usually, the reservoir sections with good physical properties and low fracture pressure are pressed first, and then high-strength water-soluble temporary plugging agent is injected to plug the fractured fractures, and the internal stress of the fractures is increased to force the fluid to turn, so as to promote the opening of secondary fractures and achieve the purpose of pressing open new fractures. Multiple injections of temporary plugging agent can promote the opening of multiple secondary fractures, eventually achieving the relatively balanced expansion of multiple fractures and cutting dense reservoirs to the greatest extent. Figure 1 below is the mechanism diagram of temporary plugging to fracturing technology at the seam.

Assuming that the fracture pressure values of different perforation positions in horizontal wells are different, the corresponding fracture pressures are 20MPa, 25MPa, 30MPa and 35MPa respectively. When the bottom hole pressure reaches 20MPa, the first fracture is first pressed open; Subsequently, temporary plugging agent was injected to temporarily plug the seam of No.1 fracture. Pressure was suppressed in the wellbore, and the bottom hole pressure began to rise. When the bottom hole pressure rose to 25MPa, the second fracture was pressed open. Continue to inject temporary plugging agent to block fracture No.2, suppress pressure in the wellbore, and the bottom hole pressure continues to rise. When the bottom hole pressure rises to 30MPa, the third fracture is pressed open, and so on. The condition for interlayer diversion is that the bottom hole pressure increment is greater than the interlayer fracture pressure difference.

Figure 1. Flow chart of temporary plugging to fracturing at seam opening
2.2. Micro-steering Mechanism of Temporary Blocking Agent

Degradable particulate temporary plugging agent has played an important role in fracturing reconstruction of many conventional and unconventional reservoirs and achieved good stimulation effect. Particle temporary plugging agent can plug perforation holes, cracks or acid-etched channels and withstand a considerable pressure difference. Its microscopic temporary plugging mechanism is mainly realized through "jamming" and "plugging". "Blocking" is the first stage of forming temporary blocking. Larger particles in the "blocking" stage have already formed a relatively stable blocking structure, but the purpose of temporary blocking cannot be completely achieved. In the following "blocking" stage, small particles need to further enter the "blocking" structure to fill gaps and form filter cakes on the surface and inside of the "blocking" structure to achieve the purpose of complete blocking (Figure 2).

![Microscopic mechanism of temporary plugging agent plugging](image)

Figure 2. Microscopic mechanism of temporary plugging agent plugging (a) plugging process (b)

In addition, when using small particle (powder) temporary plugging agent for far-field steering, attention should be paid to the reasonable combination of temporary plugging agent and propping agent. As shown in Figure 3:

![Retention of temporary plugging agent and proppant in hydraulic fracture](image)

Only temporary plugging agent, cracks closed

Temporary plugging agent and proppant coexist to provide effective oil well passage

Figure 3. Retention of temporary plugging agent and proppant in hydraulic fracture

2.3. Optimization of Temporary Blocking Agent Dosage and Proportioning Design

In the process of temporary plugging to fracturing, it is very important to determine the total amount of temporary plugging agent. Here we mainly calculate the total mass of temporary plugging agent based on indoor strength test. In the laboratory test of temporary plugging agent, we have found that in the process of temporary plugging, the breakthrough pressure increases with the increase of the length of temporary plugging agent slug, and the breakthrough pressure gradient also increases with the increase of the concentration of temporary plugging agent.

| Concentration of temporary plugging agent | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
|-------------------------------------------|----|----|----|----|----|----|-----|
| Breakthrough pressure gradient MPa/m      | 3.8| 5.7| 8.1| 14.1| 19 | 33.5| 47  |
According to the above test data, it can be found that the breakthrough pressure gradient of temporary plugging agent with different concentration is different, and with the increase of concentration, its breakthrough pressure gradient obviously increases.

The proportion design of temporary plugging agent includes the concentration and granularity proportion design of temporary plugging agent. Temporary plugging and diversion fracturing technology mainly includes four parts in the construction process: fracturing fluid carries temporary plugging agent from the surface to the bottom of the well, bridging and plugging with temporary plugging agent, diversion and pressure to open new cracks, and putting into production. Better fluid migration effect is an important step to realize reservoir fracturing reconstruction. By using coupled computational fluid dynamics (CFD) and discrete element method (DEM) numerical simulation, the parameters controlling the fluid transfer process can be better understood.

3. Mathematical Model of Flow Simulation

In the simulation process, the fluid is taken as a continuous medium and the temporary plugging agent particles are taken as discrete phases. Considering the relative motion between particles, between particles and fluid, as well as the relative motion of turbulent diffusion, the interior of each phase has its own unique dynamic properties, such as liquid viscosity, collision and friction between particles in the solid phase, and there is coupling effect between each phase. As a multiphase system, the conservation equation of each phase is coupled through the interaction between phases.

3.1. Fluid model

Mass conservation equation:
\[
\frac{\partial}{\partial t}(\rho \varepsilon) + \mathbf{\nabla} \cdot (\rho \varepsilon \mathbf{\mu}_t) = 0
\]

Where: \( \rho \) — liquid phase density; \( \varepsilon \) — liquid phase concentration; \( \mathbf{\mu}_t \) — liquid phase velocity.

Momentum conservation equation:
\[
\frac{\partial}{\partial t}(\varepsilon \rho \mathbf{\mu}_t) + \mathbf{\nabla} \cdot (\varepsilon \rho \mathbf{\mu}_t) = \varepsilon \mathbf{\nabla} \cdot \mathbf{\tau}_t + \varepsilon \rho g + \varepsilon \mathbf{\nabla} P - \beta (\mathbf{\mu}_t - \mathbf{\mu}_s)
\]

Where: \( g \) — gravitational acceleration; \( P \) — liquid phase pressure; \( \beta \) — liquid-solid two-phase drag coefficient; \( \mathbf{\tau}_t \) — liquid stress tensor.

3.2. Turbulence model

Turbulence is a three-dimensional unsteady flow, and the flow is very complicated. In turbulence, the changes of various physical parameters such as temperature and pressure of fluid are random in time and space. This simulation uses a two-equation eddy viscosity model, the standard \( k - \varepsilon \) model.

The turbulent kinetic energy \( k \) and turbulent dissipation rate equation \( \varepsilon \) of the fluid in the turbulence model can be expressed in the following form:

The developed \( k - \varepsilon \) equation model is applied to calculate the turbulent viscosity coefficient \( \mu_t \). In the \( k - \varepsilon \) two-equation model, the turbulent viscosity coefficient of the fluid is:
\[
\mu_t = c_{\mu} \rho \frac{k^2}{\varepsilon}
\]

Where \( k \) is the turbulence kinetic energy of the fluid, \( \varepsilon \) is the dissipation rate of the fluid turbulence kinetic energy, and \( c_{\mu} \) is the turbulence model constant. Fluid turbulence kinetic energy is as follows:

\[
P \frac{\partial k}{\partial t} + \rho \mathbf{\nabla} \cdot (\mathbf{v} k) = \mathbf{\nabla} \left( \frac{\mu_t}{\sigma_k} \cdot \mathbf{\nabla} k \right) + G_k - \rho \varepsilon
\]
\[ \rho \frac{\partial \varepsilon}{\partial t} + \rho \nabla \cdot (\varepsilon \mathbf{v}) = \nabla \cdot \left( \frac{\mu}{\sigma_k} \nabla \varepsilon \right) + c_i G_k \varepsilon_k - \rho c_{2} \frac{\varepsilon^2}{k} \]  

(5)

According to Boussinesq's calculation:

\[ G_k = \mu \left[ \frac{\partial \mu}{\partial y} + \frac{\partial v_i}{\partial y} + 2 \left( \frac{\partial \mu}{\partial x} \right)^2 + 2 \left( \frac{\partial v_i}{\partial x} \right)^2 \right] \]

(6)

The constants in the equation are shown in Table 2.

| \( c_1 \) | \( c_2 \) | \( c_\mu \) |
|---|---|---|
| 1.44 | 1.92 | 0.09 |

3.3. Particle model

The discrete particle model treats particles as solid phase, so Lagrange-Euler coordinates are adopted. Through the calculation of fluid-solid interaction and particle collision for all particles, the motion state of particles can be tracked.

The discrete particle tracking model assumes that the solid particles are in heterogeneous flow, and the particles are regarded as hard balls, far away from the flow boundary. The Reynolds number of the relative motion between the solid particles and the fluid is very small, and the particle size is very small and negligible. The momentum equation is as follows:

\[ \frac{du_i}{dt} = \left( 1 - \frac{\rho f}{\rho_p} \right) g_i + \frac{\rho f}{\rho_p} \frac{D u_i}{Dt} - \frac{\rho f}{2 \rho_p} \frac{d}{dt} \left( u_i - u_r \right) - \frac{18 \mu}{\rho_p d_p^2} (u_i - u_r) - \frac{9}{\rho_p d_p} \sqrt{\frac{\rho f}{\pi}} \int_0^\tau \frac{d}{\tau} \left( u_i - u_r \right) d\tau \]

(7)

The items on the right side of the equation are floating force, fluid force (pressure gradient and viscous stress), additional mass force and Stokes drag force. In this two-phase flow simulation, only drag force and floating force need to be considered.

The general form of towing force is:

\[ F_{\text{Stokes}} = \frac{18 \mu}{\rho_p d_p^2} (u_i - u_r) \]

(8)

Where the friction factor \( f \) is written as:

\[ f = 1 + 0.15 \Re^2 + 0.0175 \Re^{1.5} \left( 1 + \frac{4.25 \times 10^{-4}}{\Re^{1.6}} \right)^{-1} \]

(10)

Particle Reynolds number is defined by the following formula:

\[ \Re_p = \frac{\rho f u_i - u_r d_p}{u} \]

(11)
\[
\frac{\partial \alpha}{\partial t} + \frac{\partial \alpha u_j}{\partial x_j} = 0
\]

(12)

\[
\frac{\partial \alpha}{\partial t} + \frac{\partial \alpha u_j}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \Pi_j - \tau_j \right) + F_b - \overline{F}_p
\]

(13)

\[
\frac{Du_{pe}}{Dt} = -f_d \frac{9 \mu}{2 \rho D_p} \left( u_n - u \left[ x, (t) \right] \right) + g_i + F_{fx}
\]

(14)

\[
f_d = 1 + 0.15 \text{Re}_p^{3/2}
\]

(15)

Where \( \alpha \) is the liquid content and the sum of the liquid content and the solid content is 1. Continuous phase velocity is \( \mu, \mu_p \) is particle velocity, \( \text{Re}_p \) is particle Reynolds number, \( \Delta \text{U}_{f-p} \) is relative velocity between particle and fluid, \( \Pi \) is the sum of viscous stress \( \sigma \) and pressure \( p, \tau \) is turbulent stress tensor (depending on whether the turbulence model used in simulation is Reynolds time-average equation, large eddy simulation or super large eddy simulation), \( F_b \) is the volume force, \( F_p \) is the momentum exchange between fluid and solid in unit volume, the viscous turbulent diffusion mechanism in fluid is considered here, and \( F_c \) represents the stress of collision between particles.

When the particle concentration is higher than 1%, particle collision cannot be ignored. The models include Snidel collision pressure model and Jackson friction pressure model.

The collision pressure model is defined as follows:

\[
P_p = \frac{p_i \alpha_p^\beta}{\max \left[ \alpha_{p,cp} - \alpha_{p,c} \left( 1 - \alpha_p \right) \right]}
\]

(16)

Both \( P_p \) and \( \beta \) are constants, \( \alpha_p \) is much larger than \( \alpha_{p,cp} \) , and \( \varepsilon \) is set as \( 10^{-7} \).

The friction pressure model is defined as follows:

\[
P_p = \begin{cases} 
0, & \text{if } \alpha_p < \alpha_{p,min} \\

\frac{F \left( \alpha_p - \alpha_{p,min} \right)^\gamma}{\max \left[ \left( \alpha_{p,cp} - \alpha_p \right)^s, \varepsilon \left( 1 - \alpha_p \right) \right]}, & \text{if } \alpha_p \geq \alpha_{p,min}
\end{cases}
\]

(17)

Where \( P_p \) -collision pressure; \( \alpha_p \) -particle concentration; \( \alpha_{p,cp} \) -critical particle concentration of dense phase flow; \( \alpha_{p,min} \) -minimum particle concentration.

4. Summary

(1) In the process of temporary plugging and fracturing at the seam, the condition of interlayer steering is that the bottom hole pressure increment is greater than the interlayer fracturing pressure difference.

(2) The effective temporary plugging modification at present must reasonably mix temporary plugging agents with different particle sizes to achieve the purpose of temporary plugging.

(3) The design purpose of pressure-holding steering cannot be completely realized in the "blocking" stage, so there is the "blocking" stage.

References

[1] Can, C. Temporary Plugging, Diverting and Acid Fracturing Technology Used in Carbonate Reservoirs of Puguang Gasfield. J. Oil Drilling & Production Technology 2019, 41(2): 230-235
[2] Tao, Z. Application of Fiber Temporary Plugging and Turning Fracturing Technology in Fractured Reservoir. J. Sino-Global Energy 2019, 06:47-53.
[3] Binfeng Sun. Exploration of Multistage Temporary Plugging Turning Repeated Fracturing Fracturing Technology and Its Application in Henan Oil field. J. Petroleum Geology and Engineering 2018, 32(5):107-109.
[4] Jincheng, M. Research and Development of Temporary Plugging Repeated Fracturing Turning Technology. J. Applied Chemical Industry 2018, 47(10):2202-2206.
[5] Yapei, X. Analysis of Turning Ability and Mechanics Mechanism of Cashmere Capsule Temporary Plugging to Fracture. J. Oil Drilling & Production Technology 2018, 40(5):633-640.
[6] Xuewu, Y. Research and Application of Temporary Plugging and Turning Fracturing Technology in Extra-Low Permeability Sandstone Reservoir. J. Petrochemical Industry Application 2019, 38(7):62-65.