Study on Filtration and Damage Characteristics of Modified Dry CO2 Fracturing Fluid in Shale Gas Reservoir

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Abstract. The filtration and damage characteristics of modified dry CO2 fracturing fluid in the shale is studied in this paper. The results show that the modified dry CO2 fracturing fluid has good leak-off characteristics. Compared with liquid CO2, supercritical CO2 has a better permeation and diffusion capacity in the porous medium. The damage rate of the modified dry CO2 fracturing fluid to shale core is only between 0.63%-3.84% with obvious little damage. Under liquid conditions, the increase of temperature makes the fracturing fluid more harmful to shale formation.

1. Introduction
In the process of dry CO2 fracturing of shale gas reservoir, the filtration of fracturing fluid is inevitable. Because the filtrateloss of fracturing fluid makes the fracturing efficiency and fracture volume decrease. The fracturing fluid filtration mainly depends on its viscosity and wall building property. The filtration of fracturing fluid is controlled by three mechanisms: the viscosity of the fracturing fluid, the compressibility of the reservoir rock and fluid, and the wall building property of the fracturing fluid. At the same time, the fracturing fluid will make some damage to the formation[1-5]. Therefore, it is important to study the characteristics of the filtration damage of dry CO2 fracturing fluid in shale for calculating the geometric parameters of the fracture and evaluating the formation damage.

2. Experiment method
The filtration of fracturing fluid in the rock core is measured by the experiments method provided in People's Republic of China petroleum and natural gas industry standards "(SY/T6215-1996). The damage characteristics of fracturing fluid to core is tested by the method provided in the People's Republic of China oil and gas industry standard (SY/T 5107-1995).

3. Results and analysis

3.1. Filtration characteristics
The natural shale core from Ordos basin (length of 56.62 mm, 25.08 mm in diameter) is selected in this study. Four temperature point, 10℃, 20℃, 40℃and 60℃ is set and two shear rate points are 50s⁻¹
and 170 s\(^{-1}\). The experiment pressure is 10 MPa and the core of the confining pressure is 12 MPa. During the test, the pressure difference formed by fracturing fluid through core is 3.5 MPa.

### Table 1. Modified dry CO\(_2\) fracturing fluid filtration data

| Pressure/MPa | Shear rate/s\(^{-1}\) | Temperature/\(^{\circ}\)C | Tackifier concentration/% | Filtration coefficient/10\(^{-5}\)m·min\(^{-0.5}\) |
|-------------|-----------------|-----------------|------------------|------------------|
| 10          | 170             | 10              | 0                | 14.82            |
| 10          | 170             | 20              | 0                | 16.64            |
| 10          | 170             | 40              | 0                | 25.39            |
| 10          | 170             | 60              | 0                | 28.56            |
| 10          | 50              | 10              | 1.5              | 4.17             |
| 10          | 50              | 20              | 1.5              | 3.46             |
| 10          | 50              | 40              | 1.5              | 2.65             |
| 10          | 50              | 60              | 1.5              | 2.03             |
| 10          | 170             | 10              | 1.5              | 4.75             |
| 10          | 170             | 20              | 1.5              | 3.82             |
| 10          | 170             | 40              | 1.5              | 2.81             |
| 10          | 170             | 60              | 1.5              | 2.12             |
| 10          | 50              | 10              | 3.0              | 3.28             |
| 10          | 50              | 20              | 3.0              | 2.71             |
| 10          | 50              | 40              | 3.0              | 1.86             |
| 10          | 50              | 60              | 3.0              | 1.34             |
| 10          | 170             | 10              | 3.0              | 3.62             |
| 10          | 170             | 20              | 3.0              | 2.93             |
| 10          | 170             | 40              | 3.0              | 1.98             |
| 10          | 170             | 60              | 3.0              | 1.41             |

As shown in Table 1, the filtration coefficient of modified dry CO\(_2\) fracturing fluid is 1.34×10\(^{-5}\)~4.75×10\(^{-5}\) m·min\(^{-0.5}\), which is significantly lower than filtration coefficient of pure CO\(_2\). It also shows that modified dry CO\(_2\) fracturing fluid has good fluid loss characteristics. From the influence of various factors on the modified dry CO\(_2\) fracturing fluid filtration coefficient, the filtration coefficient at low temperature is significantly lower than at high temperature, which implies that fracturing fluid loss increases when the modified dry CO\(_2\) fracturing fluid reaches supercritical state after heat transfer in the ground formation. The reasons for this phenomenon mainly includes two aspects: on the one hand, the viscosity of dry fracturing fluid at low temperature is higher and activation energy can reduce at high temperature which makes dry fracturing fluid viscosity decreases, In this case, the fracturing fluid loss is controlled mainly by the viscosity. Thus filtration of dry fracturing fluid of high viscosity in shale is little; on the other hand, compared with the liquid CO\(_2\), the permeability and diffusion ability of the supercritical CO\(_2\) in porous media is stronger, which increases fracturing fluid filtration in the formation to a certain extent.

It can be seen from Table 1 that pure CO\(_2\) filtration coefficient is relative higher, with the range of 14.82~28.56×10\(^{-5}\) m·min\(^{-0.5}\). As mentioned above, tackifier improves the viscosity of CO\(_2\) and the fracturing fluid filtration performance to a certain extent. Influence of increasing of the tackifier concentration on dry fracturing fluid loss coefficient in liquid and supercritical phase is the same which is namely that increasing tackifier concentration can decrease fracturing fluid loss. That is mainly because under liquid and supercritical conditions, increasing tackifier concentration will increase the dry fracturing fluid viscosity, which will further enhance the characteristics of reducing filtration. In addition, with the increase of temperature, the influence of tackifier concentration on the filtration rate gradually decreases, which is closely related to the influence of temperature on the characteristics of CO\(_2\) increasing viscosity.
In this study 50 s$^{-1}$ is selected to simulate filtration characteristics of fracturing fluid in the formation under low shear rates, and 170 s$^{-1}$ is selected to simulate filtration characteristics of fracturing fluid in the formation under low shear rates. As shown in Table 1, filtration coefficient increases with increasing shear rates, which implies that both for liquid and supercritical state, increasing flow rates of fracturing fluid in fracture surface will increase fracturing fluid filtration. That is mainly because the increase of flow rate equivalently to a certain extent increases the filtration section of fracturing fluid on the surface of the core and reduces dry fracturing fluid viscosity. But when the temperature increases to 60℃, the influence of shear rate on filtration rate of modified dry CO$_2$ fracturing fluid begins to become very weak, and the critical temperature of filtration rate influenced by shear rate at this time is 60℃.

3.2. Core damage characteristics

When pure CO$_2$ is used as fracturing fluid to fracture the shale gas reservoir, it will not cause any damage to the formation. But when the tackifier is added to the CO$_2$, the formation may be affected. The data of modified dry CO$_2$ fracturing fluid damaging the shale core experiments under different working conditions is shown in Table 2, and it can be seen from the table that damage of modified dry CO$_2$ fracturing fluid to the shale core is relatively low, which means that the core damage rate is between 0.63%~3.84%. Compared with CO$_2$ foam fracturing fluid, clean fracturing fluid water and other water-based fracturing fluid system, modified dry CO$_2$ fracturing fluid has a low damage rate obviously on the shale core.

From the various factors affecting core damage characteristic of the CO$_2$ modified dry fracturing fluid, in the liquid condition, the damage of fracturing fluid to shale formation increases with increasing temperature. This is mainly because the viscosity of fracturing fluid decreases as temperature increases, the fluid filtrates into the formation easily and the tackifier delayed in the porous medium results in some damage to the shale. The damage decreases with increasing tackifier concentration, which is mainly because in the liquid condition fracturing fluid viscosity increases with increasing the concentration of tackifier, and a protective layer formed on the surface of shale makes the fracturing fluid not easy to deep percolation in porous medium. At the same time, as a kind of acidic fluid, CO$_2$ has excellent anti swelling effect on the core which has a protective effect on core.

| Pressure /MPa | Shear rate/s$^{-1}$ | Temperature /℃ | Tackifier concentration/wt% | Core damage rate/% |
|---------------|---------------------|----------------|-----------------------------|-------------------|
| 10            | 50                  | 10             | 1.5                         | 0.81              |
| 10            | 50                  | 20             | 1.5                         | 1.13              |
| 10            | 50                  | 40             | 1.5                         | 2.17              |
| 10            | 50                  | 60             | 1.5                         | 3.76              |
| 10            | 170                 | 10             | 1.5                         | 0.86              |
| 10            | 170                 | 20             | 1.5                         | 1.28              |
| 10            | 170                 | 40             | 1.5                         | 2.35              |
| 10            | 170                 | 60             | 1.5                         | 3.84              |
| 10            | 50                  | 10             | 3.0                         | 0.52              |
| 10            | 50                  | 20             | 3.0                         | 1.02              |
| 10            | 50                  | 40             | 3.0                         | 1.96              |
| 10            | 50                  | 60             | 3.0                         | 3.26              |
| 10            | 170                 | 10             | 3.0                         | 0.63              |
| 10            | 170                 | 20             | 3.0                         | 1.16              |
| 10            | 170                 | 40             | 3.0                         | 2.03              |
| 10            | 170                 | 60             | 3.0                         | 3.39              |
4. Conclusion
In the process of dry CO₂ fracturing of shale gas reservoirs, modified dry CO₂ fracturing fluid has good filtration characteristics, with a filtration coefficient between $1.34 \times 10^{-5}$ to $4.75 \times 10^{-5}$ m·min$^{-0.5}$. The filtration coefficient at low temperature was significantly higher than that at high temperature. Increasing viscosity of thickener or decreasing shear rate can decrease the filtration of dry fracturing fluid in liquid and supercritical state relatively. The damage rate of modified dry CO₂ fracturing fluid to shale core is only 0.63%~3.84% and it is obviously a low damage. The shear rate affects the damage of the modified dry CO₂ fracturing fluid to shale core, and the mechanism is the same as the filtration mechanism.

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References
[1] Garbis, S.J. and Taylor, J.L., 1986. The Utility of CO₂ as an Energizing Component for Fracturing Fluids. SPE Production Engineering, Sept, 351-358.
[2] Fenghour, A., Wakeham, W.A., Vesovic, V., 1998. The Viscosity of Carbon Dioxide. J. Phys. Chem. Ref. Data, 27: 31-44.
[3] Hong, L., Thies, M., Enick, R., 2005. Global Phase Behavior for CO₂-philic solids: the CO₂+ β-D-maltose octaacetate system. J. SuperCritical Fluids 34: 11–16.
[4] Gupta, A.P., Gupta, A., Langlinais, J., 2005. Feasibility of Supercritical Carbon Dioxide as a Drilling Fluid for Deep Underbalanced Drilling Operation. SPE-96992-MS.
[5] Harris, R.P., Jr., Ammer, J., Pekot, L.J., and Arnold, D.L., 1998. Liquid Carbon Dioxide Fracturing for Increasing Gas Storage Deliverability. paper SPE 51066 presented at the 1998 Eastern Regional Meeting, Pittsburgh, November 9–11.