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Comprehensive evaluation of formation damage induced by working fluid loss in fractured tight gas reservoir

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ABSTRACT

Western Sichuan tight gas reservoir is characteristic of developed natural fractures and ultra low matrix permeability. Developed fracture is beneficial for the economic and efficient development of tight gas reservoir. But it will lead to lost circulation of working fluid and induce formation damage. Lost circulation has frequently occurred during drill-in, completion and test process. Formation damage degree and damage range are the key indexes for the formation damage evaluation. To our best knowledge, few papers have been published on the comprehensive consideration of the above two indexes. In this paper, we conduct laboratory experiments and develop a mathematical model to evaluate the formation damage degree and determine the formation damage range. Based on the study results a formation damage pattern is established to analyze the mechanism and process of the formation damage induced by working fluid loss. The study results show that the average formation damage degree induced by drill-in fluid loss is 68.51% and increases to 78.70% when the kill fluid loss damage is taken into consideration. The radius of formation damage zone induced by working fluid loss is 15.8 m. The formation damage pattern is as follows: First the loss of drill-in fluid induces serious formation damage including sensitive damage, particle plugging and water phase trapping. Then the subsequent loss of kill fluid in the process of completion and test further aggravates the formation damage degree. Finally in the acidizing treatment the acidizing radius cannot exceed the damage zone radius so that the formation damage cannot be completely removed. The comprehensive evaluation and pattern of formation damage are necessary for designing reasonable reservoir protection and damage removal measures for the fractured tight gas reservoir.

1. Introduction

Formation damage is a hot topic these days as an increasing number of companies move to the exploitation of more and more challenging oil and gas reservoirs in deeper, tighter and more complex conditions (Kang and Luo, 2007; Esteban et al., 2013). Unconventional tight gas reservoir is one of the hot points of exploration and development. Globally the tight gas reservoirs mainly distribute in North America, Latin America, the former Soviet Union, Central Asia, the Middle East and North Africa (Zhang et al., 2005). There is a wide range of tight gas reservoir distribution in China Sichuan basin. Sichuan tight gas reservoir is characteristic of developed natural fractures and ultra low matrix permeability. Developed fractures are beneficial for the economic and efficient development of tight gas reservoir but they will lead to lost circulation of working fluid, which can induce serious formation damage. According to the comprehensive evaluation of formation damage and establishment of formation damage pattern, we can scientifically design reasonable reservoir protection and damage removal measures for the fractured tight gas reservoir.

The formation damage mechanisms are summarized as four primary mechanisms: (1) mechanical, (2) chemical, (3) biological, and (4) thermal (Bennion et al., 1996; Bennion, 2002; Wang et al., 2012). The mechanical formation damage includes fines migration, external particle invasion, phase trapping and blocking, glazing/mashing, geomechanics and perforation damage. The chemical damage mechanisms mainly contain clay swelling, clay deflocculation, chemical adsorption, formation dissolution, paraffins and waxes, emulsions and wettability alterations. The biological damage refers to problems induced by the introduction of bacteria and nutrient streams into a reservoir, which is commonly associated with water injection treatment. And the thermal damage mechanisms which are associated with high temperature injection

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operations include mineral transformations, dissolution, wettability alteration and thermal deposition. Formation damage degree and damage range are the key indexes for the of formation damage evaluation. To our best knowledge, few papers have been published on the comprehensive consideration of the above two indexes.

This paper takes the fractured tight gas reservoir in western Sichuan basin as the object of study. Firstly the engineering geologic characteristics and potential damage factors of the western Sichuan tight gas reservoir are analyzed. Then laboratory experiments are conducted to evaluate the degree of formation damage induced by working fluid loss and mathematical model is developed to determine the formation damage range. Based on the comprehensive evaluation, the formation damage pattern of working fluid loss damage is established.

2. Geologic characteristics and potential damage factors of fractured tight gas reservoir

The western Sichuan fractured tight gas reservoir which is located in Sichuan Basin has the burial depth of 2900–3200 m and thickness between 130 and 210 m. The reservoir lithology is a set of conglomerate rock whose main content is quartzitic conglomerate. The tight gas reservoir is characterized by abnormal low permeability (matrix permeability less than 0.1 mD), developed natural fracture, abnormal high pressure (pressure gradient of 1.59–1.74 MPa/100 m), and normal formation temperature (temperature gradient of 2.21 °C/100 m) (Xu et al., 2010; Kang et al., 2012). Logging and core analysis data show that average porosity of matrix and fracture are 3.22% and 0.62% respectively and the fracture permeability which is 2–5 orders of magnitudes higher than that of matrix is between 20.0 mD to 160.0 mD.

According to core observation and formation micro-resistivity image (FMI) logging, the in situ fracture width is between 20 and 100 μm. The area density of fracture is between 0.15 and 0.60 cm/cm^2 and the average fracture spacing is 3.2 cm, which are the features of typical fractured reservoir (Fig. 1). Lost circulation has frequently occurred during well drill-in, completion and test process in western Sichuan tight gas reservoir. Most of the gas wells have good gas show in drilling stem test, but have bad gas show in completion test. The developed natural fractures and clay minerals are the primary potential factors that induce formation damage in western Sichuan tight gas reservoir. From the results of scanning electron microscope (SEM), the reservoir clay minerals mainly include kaolinite, illite, montmorillonite and interstratified mineral of illite and montmorillonite (Fig. 2).

3. Formation damage degree induced by working fluid loss

In this paper, the formation damage degree of the western Sichuan tight gas reservoir is evaluated by the laboratory experiments of single type formation damage, drill-in fluid dynamic damage and working fluid sequential contact damage. However, the fluid sensitivity damage and phase trapping damage can only reflect the single damage type. The practical formation damage degree is the comprehensive result of all the formation damage type. So the dynamic damage evaluation is conducted to determine the comprehensive formation damage degree.

3.1. Evaluation of single type formation damage

The single type formation damage includes water phase trapping damage and sensitivity damage. They are evaluated according to the phase trapping coefficient method and the reservoir sensitivity evaluation method (SY/T 5358-2010) (You and Kang, 2009; Formation Damage Evaluation, 2010). Table 1 gives the evaluation results of water phase trapping damage and sensitivity damage of western Sichuan tight gas reservoir.

3.2. Dynamic damage evaluation of drill-in fluid

The dynamic damage evaluation experiment is conducted to determine the comprehensive formation damage degree of fluid sensitivity damage, particle invasion, water phase trapping induced by working fluid loss. It can simulate the dynamic flow state of working fluid in the wellbore during the drilling and completion process. The schematic diagram of the dynamic damage evaluation experiment can be seen in Fig. 3. The core samples and working fluid used in the experiment are taken from the western Sichuan tight gas reservoir.

The test procedures are as the follows: ① Measure the initial simulated formation-water permeability of fractured core samples in the direction of the arrow in Fig. 3. (For gas reservoirs, the regained permeability test should use gas, but the regain-permeability test with formation water can overcome the Klinkenberg correction in the gas permeability measurement.) ② Circulate the drill-in fluid in the fluid container to simulate the damage process for 60 min in the reverse flow direction to the initial permeability measurement at 3.5 MPa overbalance pressure difference and 70 °C. ③ Reverse the flow direction (back to the direction used for the initial permeability measurement), and measure the simulated formation water permeability at a range of flow gradients including the same applied pressure gradients used for the initial permeability measurement. ④ Calculate the percentage of regained permeability and permeability damage rate.

Table 2 gives the physical properties of the experimental drill-in fluid and Table 3 shows the basic physical parameters of the core samples. Table 4 shows the dynamic damage evaluation experimental results. For the fractures with the width of 30 μm–100 μm,

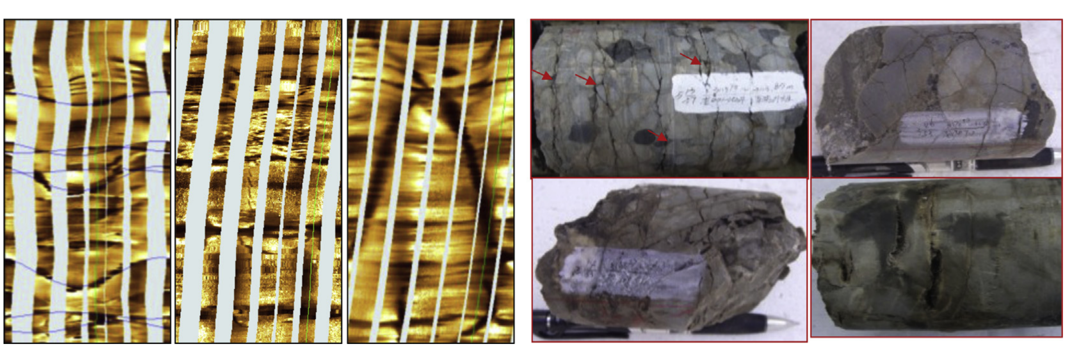

Fig. 1. Natural fractures in FMI logging and tight cores.