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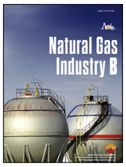

Research Article

Experimental evaluation on the damages of different drilling modes to tight sandstone reservoirs ☆

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Abstract

The damages of different drilling modes to reservoirs are different in types and degrees. In this paper, the geologic characteristics and types of such damages were analyzed. Then, based on the relationship between reservoir pressure and bottom hole flowing pressure corresponding to different drilling modes, the experimental procedures on reservoir damages in three drilling modes (e.g. gas drilling, liquid-based underbalanced drilling and overbalanced drilling) were designed. Finally, damage simulation experiments were conducted on the tight sandstone reservoir cores of the Jurassic Ahe Fm in the Tarim Basin and Triassic Xujiahe Fm in the central Sichuan Basin. It is shown that the underbalanced drilling is beneficial to reservoir protection because of its less damage on reservoir permeability, but it is, to some extent, sensitive to the stress and the empirical formula of stress sensitivity coefficient is obtained; and that the overbalanced drilling has more reservoir damages due to the invasion of solid and liquid phases. After the water saturation of cores rises to the irreducible water saturation, the decline of gas logging permeability speeds up and the damage degree of water lock increases. It is concluded that the laboratory experiment results of reservoir damage are accordant with the reservoir damage characteristics in actual drilling conditions. Therefore, this method reflects accurately the reservoir damage characteristics and can be used as a new experimental evaluation method on reservoir damage in different drilling modes.

Keywords: Drilling mode; Air drilling; Liquid-based underbalanced drilling; Overbalanced drilling; Tight sandstone; Reservoir damage; Permeability; Experimental evaluation

Compared with conventional reservoirs, tight sandstone reservoirs are vulnerable to damage during the operation of oil and gas wells due to their low porosity, low permeability, complicated pore structures and extremely small channels. Mainly caused by solid or liquid phase invasion and the reservoir sensitivity [1–3], reservoir damages may result in low or even no production [4,5]. Reservoir damages may vary in types under different drilling modes [5–7]. In overbalanced drilling, reservoir damages mainly include water lock damage, sensitivity damage and solid-phase invasion damage [8–10]. In underbalanced drilling, reservoir damages mainly include liquid-phase backwash imbibition damage [11,12], stress sensitivity damage [13,14], the damage in non-whole course underbalanced drilling [15,16], etc. Therefore, quantification of the reservoir damage degree under various damage modes is the key to the analysis of the damage to tight sandstone reservoirs. Only by correctly analyzing and predicting the types and degree of potential reservoir damages, can we effectively avoid such damages and achieve more accurate prediction of hydrocarbon productivity. In this paper, reservoir damage type and degree are evaluated through reservoir damage simulation

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experiments in three drilling modes (e.g. gas drilling, liquid-based underbalanced drilling and overbalanced drilling), in order to provide a theoretical basis for drilling mode optimization, reservoir protection and gas well productivity improvement.

1. Reservoir damages in gas drilling

According to the analysis of the geological characteristics of reservoir damages, the pore pressure of a formation drops rapidly after a reservoir is opened through gas drilling. The reservoir is exposed to increasing effective stress, which may cause stress sensitivity damage. As the gas drilling will bring about a large underbalance value, the stress sensitivity damage evaluation determines the reservoir adaptability of gas drilling.

The current stress sensitivity experiment method using the invariable pore pressure and the variable confining pressure is often not applicable to tight sandstone to some extent [17]. Therefore, this experiment adopts the invariable confining pressure and the variable pore pressure to simulate the changing process of the effective stress of a tight sandstone gas reservoir.

With the core of the Jurassic Ahe Fm in the Tarim Basin as the sample, the confining pressure was set at 90 MPa in the simulation based on the actual situation, and then the relationship between the permeability and porosity of the tight sandstone and the pore pressure was studied. The devices and cores for the experiment are shown in Fig. 1.

1.1. Experiment on the stress sensitivity of permeability

The experimental steps are as follows:

1) Select a typical core, dry it until its quality does not change, and then put it into the core tube;
2) Apply 90 MPa confining pressure on the core, close the outlet valve, and then load pressure on both ends of the core holder to 47 MPa and maintain it;
3) After a period of time, decrease the pressure of the core outlet end through the control valve to 3 MPa and maintain it, so that the seepage of high-pressure nitrogen begins under the action of the differential pressure; then measure the core permeability;
4) Repeat steps 1) to 3), to reduce the pore pressure with 10 MPa as a gradient, and measure the core permeability when the inlet pressure is 47 MPa, 37 MPa, 27 MPa, 17 MPa and 7 MPa respectively;
5) Then gradually restore the inlet pressure to 7 MPa, 17 MPa, 27 MPa, 37 MPa and 47 MPa, and measure the permeability recovery after stress sensitivity damage

The average pore pressure is the average of the inlet and the outlet pressures [18]. The permeability data under the different effective stress (65 MPa, 70 MPa, 75 MPa, 80 MPa and 85 MPa) during the change of the pore pressure (25 MPa, 20 MPa, 15 MPa, 10 MPa and 5 MPa) are obtained, as shown in Tables 1 and 2.

No. 1 and 2 cores were selected to perform a contrastive analysis of the permeability during the change of matrix core pore pressure. As the pore pressure decreased, the corresponding effective stress increased. The relationship between the effective stress and permeability of No.1 and 2 cores (as shown in Fig. 2) were obtained from the experimental data of Tables 1 and 2. It can be seen that the core permeability decreases rapidly as the pore pressure at the inlet end of the test device decreases. Then as the pore pressure at the inlet end increases, the core permeability increases slowly. When the pore pressure increases from 5 MPa to 25 MPa, the permeability damage rate of No.1 core is 7.44% and the permeability damage rate of No. 2 core is 11.92%.

Table 1
Permeability data during effective stress increase.

Core no.	Permeability during effective stress increase/mD				
	65 MPa	70 MPa	75 MPa	80 MPa	85 MPa
1	0.0062	0.0053	0.0045	0.0038	0.0033
2	0.0056	0.0045	0.0036	0.0029	0.0025
3	21.4371	14.6081	11.1639	8.4917	6.532
4	15.38	10.7482	7.8385	6.3539	4.691

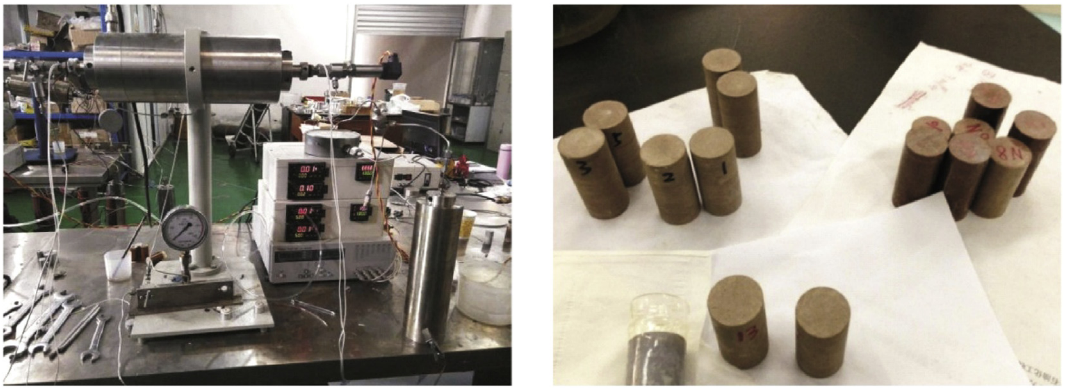

Fig. 1. Devices and cores for the stress sensitivity experiment.

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