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Numerical simulation of transport mechanisms for cyclic high-speed injection and production in fractured-vuggy underground gas storage

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Underground gas storage (UGS) exhibits various transport mechanisms due to their multi-cycle injection and production, often overlooked in numerical simulations. In fractured-vuggy UGS, certain mechanisms may have a stronger effect. L underground gas storage is crucial to China's first fractured-vuggy UGS group. A simulation study was conducted to investigate the effect of three transport mechanisms—stress sensitivity, relative permeability hysteresis, and high-speed non-Darcy effect of the fractured-vuggy UGS L during high-speed injection and production. Based on the geological model of the L UGS, the history matchings were separately conducted with and without considering transport mechanism to ensure model accuracy and elucidate the significance of transport mechanisms (as shown in Fig. 1). The multi-component fluid characterizations were implemented separately using the Peng-Robinson equation of state to perform the compositional simulation.

Our study found that stress sensitivity resulted in a 3.31% reduction in storage capacity and a 6.07% decrease in working gas volume. Relative permeability hysteresis led to a 9.05% decline in storage capacity and a 4.09% decrease in working gas volume. The high-speed non-Darcy effect only caused a 0.16% reduction in storage capacity but led to a 4.19% decrease in working gas volume. With increased injection and production cycles, the storage capacity steadily rises. After 25 cycles, there was a 3.97% increase in storage capacity. Stress sensitivity increased the capacity increment to 4.66%, while relative permeability hysteresis and high-speed non-Darcy effect raised the increment to 6.05% and 4.13%, respectively. The greater the impact of the transport mechanisms on storage capacity and working gas volume, the more significant the increase in storage capacity. However, this increase in capacity is attributed to the rise in cushion gas volume and does not reflect an increase in working gas volume. The coupling of stress sensitivity and relative permeability hysteresis resulted in a reduction of 6.51% in storage capacity and a decrease of 11.65% in working gas volume. The coupling of these two mechanisms reduced the loss in storage capacity but amplified the decline in working gas volume. We analyzed six effects resulting from the coupling of two mechanisms, as illustrated in Fig. 2. The coupling of the three mechanisms resulted in a reduction of 6.53% in storage capacity and a decrease of 13.44% in working gas volume (as shown in Fig. 3). Coupling with the high-speed non-Darcy effect had no extra coupling effect on storage capacity but led to a further decline in working gas volume. The mutual influence relationships among the three mechanisms are depicted in Fig. 4.

This study presents the utilization of compositional simulation to investigate the coupled effect of stress sensitivity, relative permeability hysteresis, and high-speed non-Darcy effect, as well as the coupled effects of stress sensitivity with relative permeability hysteresis on the operation of fractured-vuggy UGS. It comprehensively quantifies the varying degrees of influence exerted by different transport mechanisms on the operation of UGS. The study offers guidance for optimizing operational strategies for the UGS L and other similar UGS converted from fractured-vuggy reservoirs.

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