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Feasibility study of the inversion method for non-uniform hydrate saturation distribution based on ensemble Kalman filter algorithm

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Field tests and laboratory experiments indicate that the spatial distribution of hydrate saturation in hydrate reservoirs is non-uniform. This non-uniform distribution significantly impacts the reservoir's temperature changes, and gas and water production rates during reservoir development. Currently, the primary methods for determining hydrate saturation distribution in porous media are nuclear magnetic resonance (NMR) and computed tomography (CT) scanning. However, these methods have limitations such as small detection ranges, high costs, and the necessity of interrupting experiments. During depressurization exploitation of hydrate reservoirs, abundant data on gas and water production, as well as temperature and pressure monitoring, are available. These highly reliable observational data vary with changes in hydrate saturation distribution, providing the possibility of using inversion methods to determine this distribution.

This study first conducts secondary development of the Tough+Hydrate simulator. Energy and mass conservation equations are separately constructed for the matrix and high-conductivity channels after reservoir stimulation. The transfer of mass and heat in the matrix and high-conductivity channels was characterized using the discrete fracture method. A numerical simulation method for reservoir stimulation assisted depressurization development of hydrate reservoirs was established and implicitly solved. Then, by combining the ensemble Kalman filter algorithm with the simulator, the inversion method of the hydrate saturation distribution was built and then validated using three cases: core scale depressurization development, hydraulic fracturing assisted depressurization development, and radial well stimulation assisted depressurization development. The impact of the number of observation points on the inversion results also was investigated. Finally, based on

the observation data of Masuda's classic experiment, the inversion method was used to obtain the distribution of hydrate saturation in the core of Masuda's experiment successfully.

Research results indicate that the established inversion method continuously assimilates observational data in the ensemble. Hydrate saturation distributions obtained through inversion in the three cases tend to approach the preset distributions, demonstrating the reliability of the inversion method. The quantity of observational data has a certain influence on inversion results; more observational data lead to the assimilation of more information, resulting in hydrate saturation distributions closer to the actual values. Inversion results based on Masuda's experimental data reveal a strong non-uniformity in hydrate saturation distribution within the core, with a relatively high hydrate saturation zone in the central region and lower hydrate saturation at the inlet and outlet ends.

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