Theoretical Analysis and Numerical Simulation of Multi-Fields Coupled Variation During Deepwater Hydrate-Bearing Reservoir Exploitation

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Abstract: Natural gas hydrate is regarded as a kind of potential alternative energy resource and attracts the attention all over the world. Geological surveys have found that most natural gas hydrates are buried at the bottom of the sea. Several development methods, such as depressurization, thermal stimulation and inhibitor injection are proposed gradually on the basis of hydrate special properties, obtaining certain trial-produce performance. It is of great significance to learn the flow rules underground for production safety guarantee and efficiency improvement. However, the special phase transition of hydrate between solid and fluid accompanied by energy and mass change makes it difficult to predict and describe the parameters variations during hydrate-bearing exploitation. Since the hydrate is always sensitive to surrounding conditions, the disturbance of ambient pressure and temperature can change the corresponding phase equilibrium temperature, pressure and even phase transition rate. On the one hand, hydrate dissociation/reformation is an endothermic/exothermic reaction and releases/consumes large amount of gas in the limited space, reacting on the ambient pressure and temperature. On the other hand, hydrate phase transition also induces particles (hydrate, ice, sand, etc.) separation, aggregation and migration, altering the original hydrate saturation, reservoir properties (thermal conductance, permeability, skeleton structure, bonding strength, etc.) and multiphase flow. Then the heat and mass transfer in porous medium driven by the pressure difference and temperature difference influences the ambient conditions. Therefore, it is a complex coupled process with a series of variables. In this research, interaction mechanism between hydrate phase transition and porous media properties has been analyzed through influencing factors and the coupled relationship between multi-fields (containing temperature field, pressure field and seepage field) has been obtained. Taking the deepwater characters into consideration, the wellbore temperature and pressure distribution has been predicted by numerical simulation firstly as the boundary conditions of neighborhood hydrate-bearing reservoir. After proposing assumptions for simplification, the multi-flow model in hydrate- bearing reservoir has been built. Then applying production data referred from existed literatures and field reports, the multi-fields coupled variations during exploitation of hydrate-bearing reservoir have been simulated by the multi-flow model.

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The results indicated that although the temperature gradient of sea water reduce the wellbore temperature and the pressure gradient increase the wellbore pressure gradually, the ambient conditions are still disturbed significantly and become closer to hydrate phase transition requirements (10~30 MPa, 10~60℃). The near- wellbore temperature increases and pressure decreases earliest, and the variation area spreads towards the further reservoir. As time goes on, the disturbed zone becomes larger and larger but spread rate becomes lower and lower. Combining the reservoir temperature and pressure distributions with the hydrate phase equilibrium, corresponding hydrate phase transition can be analyzed and natural gas production can be estimated, providing a certain theory support for deepwater hydrate-bearing reservoir multi-fields prediction and efficient production.

Keywords: Deepwater; hydrate-bearing reservoir; heat and mass transfer; multi-fields coupled variation; numerical simulation