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Coupled Thermal-Hydro-Mechanical-Chemical Modeling for Time-Dependent Anisotropic Wellbore Stability Analysis

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Wellbore instability is one of the most serious drilling problems increasing well cost in well construction processes. It is widely known that many wellbore instability problems are reported in shale formations where water sensitive clay mineral exist. The problems become further complicated when the shale exhibits variation in strength properties along and across bedding planes. In this study, a coupled thermal-hydro-mechanical-chemical (THMC) model was developed for time-dependent anisotropic wellbore stability analysis considering chemical interactions between swelling shale and drilling fluids, thermal effects, and poro-elastoplastic stress-strain behaviors.

The THMC simulator developed in this work assumes that the shale formation behaves as an ion exchange membrane where swelling depends on chemical potential of drilling fluids invading from the wellbore to the pore spaces. The time-dependent chemical potential changes of water within the shale are evaluated using an analytical diffusion equation resulting in the evolution of swelling strain around the wellbore. On the other hand, the thermal and pressure diffusion equations are evaluated numerically by finite differences. The stress changes associated with thermal, hydro, and chemical effects are coupled to the 3D poroelastoplastic finite element model. The effects of bedding planes are also taken into account in the FEM model through the crack tensor method in which the normal and tangential stiffnesses of the bedding planes have stress dependency. The failure of the formation rock is judged based on the critical plastic strain limit.

The numerical analysis results indicate that the rock strength anisotropy induced by the existence of bedding planes is the most important factor influencing the stability of the wellbore among various THMC process parameters investigated in this work. The numerical results also reveal that an established theory to orient the wellbore in the direction of the minimum principal stress is not always a favorable option when the effect of the anisotropy of in-situ stresses and the distribution angle of bedding planes cancel out each other. Depending on both the distribution angle of bedding plane and ratio of the vertical to the horizontal stress, the trend of minimum mud pressure showed a great variation as predicted by the yield and failure criterion implemented in the model. Furthermore, the analysis results reveal that the distribution and evolution of plastic strains caused by the THMC processes have the time dependency, which can be controlled by the temperature and salinity of the drilling fluids.

The numerical wellbore stability analysis model considering shale swelling and bedding plane

effects provides an effective tool for designing optimum well trajectories and determining safe mud weight windows for drilling complex shale formations. The time-dependent margins of safe mud weight window of drilling can be fine-tuned when the interaction among various parameters is fully considered as the THMC processes.