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Electrically Enhanced Shale Oil Productivity Considering Nano-Confined Phase Behavior and Micro-Fracture Dilation

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Abstract : Shale oil is the dominant contributor to global unconventional oil resource production. Compared to conventional oil and gas, shale oil productivity is significantly constrained by nano-confinement effects, which hinder oil flow from nano-pores (primary storage locations) to micro-fractures (main flow channels). Besides, the compact micro-fractures of low permeability cannot provide efficient flow channels to production well. These constraints result in inefficient oil displacement and fast production decline. Increasing temperature can simplify the phase change process and potentially enhance micro-fracture permeability by dilation. This study explores the potential of electrical heating enhanced shale oil flow by wind power transition, which can unlock the oil from tight shale oil formations. A non-isothermal numerical simulation approach is developed to model the thermal effects on shale oil flow dynamics. The model integrates nano-confined phase behavior, phase transition mechanics, multi-scale flow processes, heat transfer, and fracture dilation. A modified equation of state accounts for capillary pressure, adsorption, and nano-confinement. A coupled thermo-mechanical phase-field model simulates thermally induced micro-fractures. Model validation is performed by comparing simulation results against nano-scale experimental data. Further validation is conducted by the oil production performance comparison of simulation results and field history. Comparative analysis of the isothermal production method and electrical heating improvement approach in shale oil production confirm that elevated temperature improves oil phase consistency from nano-pores to fractures and increases micro-fracture permeability. As a result, oil flow is accelerated from tight formation to production well and thermal treatment makes a promising approach for shale oil production enhancement. Numerical simulation demonstrates that heat is primarily generated in the zone of high salinity saturation due to its high dielectric values. Meanwhile, the in-situ oil is simultaneously heated by conduction. Computation of energy efficiency provides that 100 % electric power can be transformed into heat in a shale oil formation by the ohm effect. Key results show that pore size dictates the target heating temperature, while shale mineral thermal expansion coefficients influence fracture initiation and dilation. Additionally, simulations indicate that a temperature increase of approximately 100°C significantly enhances shale oil mobility by improving phase change consistency from nano-pores to fractures and micro-fracture permeability. This study provides a computation framework for evaluating the effectiveness of thermal treatment in overcoming shale oil nano-confinement and compact fracture challenges.

Keywords : shale oil, thermally enhance oil recovery, nano-confinement, phase behavior, electric excitation
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