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Analytical Modeling of Stimulation Fluid Temperature for Hydraulic Fracturing Design

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In hydraulic fracturing of unconventional reservoirs, the stimulation fluid is injected at a different temperature than initial reservoir temperature. The dynamic temperature profile of stimulation fluid during the treatment can provide critical information for fracturing design. In this work, an analytical solution to model the stimulation fluid temperature profile during hydraulic fracturing is presented. This analytical model is derived from the energy balance equation for fracture system coupled with a fracture propagation and fluid leak-off model. The procedure to obtain this analytical solution from the governing equation involve Method of Characteristics with valid assumptions. Several important features of the treatment have been preserved, including dynamic fluid leak-off and stimulation fluid velocity inside the fracture. Simple procedures to apply this solution are presented, which provide a convenient way to relate the warm-back temperature profile to the fracture, reservoir, and fluid properties.
The results of the analytical model are presented in terms of the temporal temperature variation inside the fracture. These results are compared and validated in multiple cases with numerical results from commercially available simulation software, as well as simulation results reported in the literature. We identify and analyze the major mechanisms contributing to the temperature signal, which involves the conduction to surrounding stimulated reservoir volume and convection associated with fluid leak-off and varying fluid velocity inside the fracture. The dynamic temperature profile for individual fracture and associated stimulated zone are strong functions of fracture and fluid properties, which include the leak-off coefficient, fracture pore volume, heat transfer coefficient between fracture and stimulated reservoir volume, and density and specific heat of the stimulation fluid. The effect of these factors on temperature distribution is investigated in the sensitivity analysis, which produces several dimensional parameters from this analytical solution. Various types of fracturing treatment design are applied to the developed solution to show its feasibility.
Despite many previous numerical studies on the same issue, this analytical solution brings direct insight into physics behind the stimulation fluid temperature profiles including fracture propagation and fluid leak-off. Besides multiple applications mentioned above, this work can be used as a theoretical basis for a potential analytical approach to address the proceeding warm-back temperature analysis after hydraulic fracturing.

References

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