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Integration of Pressure Transient Data into Reservoir Models using the Fast Marching Method

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Calibration of reservoir model characteristics by integration of well test data remains an important research topic. Traditional approaches to well test interpretation have relied upon simple homogeneous reservoir models, while the industry's ability to develop more detailed and more heterogeneous static reservoir models has increased significantly. Pressure and rate data recorded at production (or injection) wells is readily available and can provide additional dynamic conditioning of these static models. Well test data has been recognized as an effective tool that can be used to describe transient flow behavior in petroleum reservoirs. It is also closely related to the drainage volume of the well and the pressure "front"propagation in the subsurface.

Traditional analytic means of estimating reservoir permeability relies on an interpretation of the diagnostic plot of the well pressure and production data, which usually leads to a bulk average estimation of the reservoir permeability. Typical pressure interference tests involve injecting or producing fluid from one well while the pressure is recorded in another or more observational wells, where well pressure response can be affected by both geometry and flow regimes of the reservoir. Although only applicable to idealized models, the analytic approach provides the simplest methodology to obtain reservoir parameters through analysis of pressure changes. When more detailed characterization of reservoir heterogeneity is needed, a numerical inversion technique is required to integrate the observational data into reservoir models. Inverse methods for reservoir parameter estimation during history matching rely on establishing a robust forward model and then determining an objective function to be minimized. Generation of sensitivity coefficients for reservoir properties in all grid cells of the model is required, which becomes quite expensive as the model grows to a large size.

We utilize the concept of the "diffusive time of flight"(DTOF) to formulate an asymptotic solution to the diffusivity equation that describes transient flow behavior in petroleum reservoirs. The DTOF reduces the three-dimensional diffusivity equation to an equivalent one-dimensional form and is calculated by solving the Eikonal equation via the Fast Marching Method (FMM). Our method is tested on a two-dimensional synthetic heterogeneous reservoir model and applied to the three-dimensional Brugge field, where a single well with constant flow rate is simulated. The well test derivative is shown to be inversely proportional to the drainage volume and is treated as the objective function for inversion. Its sensitivity coefficients to the reservoir parameters are formulated analytically by taking the functional derivative of the Eikonal equation. The major advantage of formulating sensitivity coefficients using the FMM is its great computational efficiency while inversion is conducted, which is three orders of magnitude higher than numerical perturbation. With an additional constraint to honor the initial model, our inverse modeling approach will adjust the reservoir model to obtain permeability as a function of distance from the well within the drainage volume. It provides a modification of reservoir permeability both within and beyond the "depth of investigation".

References

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