SUPERELEMENT METHOD OF MULTISCALE MODELING OF PETROLEUM RESERVOIRS

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A new approach is proposed for two-stage modeling of different-scale flows during oil reservoir development. At the first stage, the problem of global flooding of the reservoir is solved by the finite volume method on large unstructured super element (SE) grids with a step equal to the inter-well distance (200-500 m). Such grids are quite sufficient to resolve the average smooth fields of pressure and saturation and provide significant (by hundreds of times) acceleration in comparison with the traditionally used grids with a step of the order of 30-50 m. The description of fast small-scale flows in the second stage of modeling is performed on local grids of high resolution. One-way relation between the problems of the both stages is to set the initial and boundary conditions for the local problems.

Two-phase flow in petroleum reservoir is described by the total flow model. The model includes a parabolic equation for the pressure p and a hyperbolic equation for the saturation s. The coefficients of the equations are determined by the scalar field of the absolute permeability k and by the relative phase permeability functions $k_w(s)$ and $k_o(s)$.

With the transition to coarse super element grids, the general structure of the two-phase flow equations is preserved. However, in order to maintain the high accuracy of the calculations, an effective tensor of absolute permeability $\underline{K}$ and a pair of modified phase permeabilities $K_w(S)$ and $K_o(S)$ as functions of the average saturation S in the SE are constructed using special methods of local upscaling for each SE.

Upscaling of absolute permeability is based on solving auxiliary three-dimensional problems of steady state single-phase flow on the fine grids in the area of each SE. The components of the effective permeability tensor are sought from the solution of the problem of minimizing the functional of the deviation of the averaged and approximated fluxes across the faces of the SE. For flux approximation integral-interpolation procedures of the super element numerical scheme are used. The method takes into account the true geometry of the SE and allows the specification of an arbitrary set of boundary conditions for reflection of typical variants of the flow structure.

The functions $K_w(S)$ and $K_o(S)$ for each SE are constructed in a parameterized form by the method of local dynamic upscaling. Two-dimensional problems of non steady state two-phase flow are solved on a fine computational grid in the vertical section of the reservoir representative for the SE. The parameters of the functions are sought from the solution of the problem of minimizing the functional of the deviations of the averaged and approximated on instantaneous S phase fluxes through the SE faces.

The application of the superelement model is demonstrated by simulating 50 years of development of an area of the Romashkinskoye oilfield containing 850 wells, within 4 minutes of the machine time.