Ph.D. Thesis

Macrokinetics of wetting inversion by surfactant injection in porous media

Research description

To produce oil from a geological reservoir, one injects water to displace oil mechanically. The displacement becomes however very difficult if the rocks are oil-wet, since oil is highly glued to the walls, so that water is unable to detach it. The only solution in this case is to inverse wetting, which may be reached by adding surfactants in water. The efficiency of the process is determined by the characteristic kinetic time of inversion. The calculation of this time and the implementation of the kinetics of wetting inversion in the macroscopic model of two-phase flow is the main objective of the present research.

The research will consists of four main parts.

Part 1: Impact of surfactant concentration on wetting inversion

The injection of surfactants does not lead necessary to wetting inversion. Then the first problem is to determine the minimal concentration of surfactants that ensures the wetting inversion in principle. This critical concentration depends, in turn, on the properties of the rocks and the fluids. This problem can be studied numerically, by analyzing the equilibrium shapes of the meniscus before and after surfactant injection. Such an equilibrium is governed by the so-called Young-Laplace equation, which is obtained by the minimization of the free energy of all the surfaces. This is a nonlinear differential equation of the second order with respect to the vertical coordinate of the meniscus height. The presence of surfactants, which are micellar aqueous solutions, is a new element of this research, which will lead to an extended Young-Laplace model. The numerical code will be developed in Matlab to solve the ordinary differential equation for 1D stationary problem.

Part 2: development of the extended hydrodynamic equations

The essential part of the process of meniscus inversion consists of the deformation of the nanometric precursor film (a thin film just ahead of the meniscus) Unfortunately, the Navier-Stokes equations are invalid in thin nanometric films, and, moreover, their solutions diverge in the vicinity of the triple line (the line of contact of oil, water and solid). Consequently, the second part will consist of deriving an extended system of hydrodynamic equations that would be valid in thin films. This may be achieved by averaging the microscopic equations of molecular movement (the Boltzmann equations [1]) and applying various closure relationships, as for instance, the H. Grad' method of moments [2], or the method of Barnett expansion [3] over the Knudsen numbers, *Kn* (the distance between molecules divided by the domain size), or the quasi-hydrodynamic approach [4], which assumes that the distribution function remains in the non-equilibrium during a short period between two collisions. The expected result is the system of extended Navier-Stokes equations and a new boundary condition that allows a natural slip of molecules within the precursor film along the solid surface.

Part 3: Numerical analysis of the kinetics of wetting inversion on the pore scale

The third part consists of numerical modeling of the extended hydrodynamic equations obtained in part 2. The dynamics of the meniscus inversion in a single pore will be studied. The expected result is the characteristic time of inversion as the function of fluid properties, surfactant concentration and pore size. The numerical modeling of this system should take into account the multiscale structure of the system, given that the main part of the meniscus has micrometric size, while the precursor film ahead of it is nanometric. The research will be based on using the code Basilisk developed by the team of d'Alembert Institute specially to solve various multiscale problems of fluid mechanics.

Part 4: Implementation of the kinetic model of wetting inversion into the macroscopic model

The fourth part consists of implementing the kinetics of the meniscus inversion into the macroscopic model of two-phase flow. As the meniscus deformations are accompanied with some energy dissipation, it is expected that the inversion retards the meniscus propagation. This means that the macroscopic momentum equations (Darcy's law) should contain additional force responsible for such a retardation. This macroscopic force is the result of the action of the capillary forces, the forces of adhesion and the force of disjoining pressure in the precursor film. The characteristic time of the action of this new force is exactly the kinetic time of wetting inversion.

The obtained macroscopic model, which will be capable of describing the meniscus inversion, will be used to compare with experimental data of various authors obtained for oil-water-surfactants systems used in EOR.

Research organization

The research will be financed by the company Wintershall. Close contacts with the engineers of Wintershall are welcome, which intends frequent visits of doctorant between Kassel and Paris.

During the first year, the doctorant will work in a close cooperation with a post-doctoral researcher (a physicist) to develop the theoretical and numerical parts 1,2 and 3.

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Doctoral school: SMAER - Sorbonne Université.

Laboratory of attachment: Institut d'Alembert – Sorbonne Université, Paris.

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Bibliographie

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4. Sheretov Yu.V. Mathematical modelling of flow of liquid and gas on the basis of quasi-hydrodynamic and quasi-gas-dynamic equations. Ed. University of Tver, 2000.

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