Preface

Mikhail Panfilov

Received: 8 March 2010 / Accepted: 9 March 2010 / Published online: 20 March 2010
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All of us who work in the field of flow through porous media are sick of Darcy's law, relative permeability and interpenetrating continua—all these old approaches which replace the complex of interfering physical processes in pores by some empirical functions and relationships which have very diffuse and unclear physical meaning. They were developed as a temporary tool, but turn out to be so tenacious.... Tenacious and mathematically beautiful! If even so simplified physical models require a complicated mathematical apparatus then probably the optimal equilibrium between physics and mathematics is already reached? Beyond this equilibrium the mathematical models will be certainly much more complicated and most likely inefficient. This is probable. However, this cannot stop the human need to understand physics. To understand it and to set it in the frame of spectacular mathematical model.

This SI and the EUROMECH Colloquium 499 (<http://lemta.ensem.inpl-nancy.fr/euromech.html>) which has preceded it, is the result of our dissatisfaction of the current state of matter. We are not alone, several other scientific groups in the worldwide which are not presented in this SI try to develop new basis of the multiphase flow theory in porous media. The results presented in this SI are far from to be announced as the new multiphase theory, the objective of this SI is to demonstrate that several new approaches based on much deeper physics (than Buckley Leverett, for instance) may be efficiently treated mathematically. This means first of all that the authors have succeeded in formalising such non-classical physical models that describes the fluids separated from one another by multiple interfaces (like drops or films, ...), which can transform into another phase (stagnant or mobile), whose behaviour authorises the intersection of several interfaces and their partial disappearing, so that the number of phases is variable in space and time. The main method enabling formalising such processes is the diffusive interface approach (or the density functional approach) which assumes that the overall system is single-phase but the interfaces are simply the sharp transitions in fluid density (P. Papatzakov; F. Boyer et al.). The efficient flow equations for such a fluid are developed by formulating a fundamental relationship for the free energy and minimising it. The relation for free energy is adopted from the theory of phase transitions

M. Panfilov (✉)

Laboratory of Energetics and Theoretical and Applied Mechanics, Nancy, France
e-mail: mikhail.panfilov@ensem.inpl-nancy.fr

and Cahn-Hilliard theory of wetting. The paper by Papatzakos is the first which applies this approach to multiphase flows in porous media. The paper by Boyer et al. develops the non-trivial extension of this approach to three-phase fluids. The similar approach of minimisation of the free energy is applied in the paper by Silin to describe the film structures in two-phase systems. The main new element of this approach consists of formulating the functional of free energy which takes into account for the disjoining pressure.

The second efficient tool consists of introducing the elements of the percolation theory into the phenomenological approach which allows for separating different physical states of the same phase (connected or disconnected, mobile or immobile) and to efficiently describe the transitions between these states (R. Hilfer). The obtained flow equations describe immiscible two-phase flow but in terms of the much richer physics.

The papers by Jaffré and Moyne and Stemmelen are devoted to the case when two-phase gas–liquid fluid may change the number of phases due to condensation or boiling and, due to this, contains macroscopic interfaces. In (J. Jaffré) the two-phase gas–liquid fluid contains dissolved chemical components. When gas disappears then the dissolution of chemical components in the remaining liquid is impossible to describe in classical terms of the equivalence of chemical potentials between gas and liquid. The paper suggests new mathematical approach based on introducing a *complementary condition*, frequently used in the theory of optimal control, which takes into account for the probable gas disappearance.

The paper by Moyne and Stemmelen analyses the two-phase non-isothermal system under heating which leads to liquid boiling. The authors suggest new mathematical model of the process which takes into account for the presence of the macroscopic interface, which is based on the contrasting properties of gas and liquid. The model predicts oscillatory regimes of the interface which were observed experimentally.

All these papers devoted to sufficiently nonlinear multiphase flows give an excellent example of new methods and models which can be efficiently developed and which will certainly lead to the appearance of the new multiphase flow theory in the nearest future.