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Deep nanoscale desorption of gas in shale

M. Panflov¹, F.Kuchuk²

¹ LEMTA, CNRS/Université de Lorraine, Nancy

² Schlumberger Riboud Product Centre, Clamart

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It is known that gas in shale behaves differently from conventional gas: its motion is not governed by Darcy's law, its density is not controlled by thermodynamic laws, and its condensation occurs differently from that in bulk.

In our paper we reveal three other non-trivial mechanisms of gas behaviour in shale: the deep desorption, the nonlocal phenomena generated by multiscale structure of shales, and the effect of super-memory.

The deep desorption was observed experimentally [for instance, Etminan et al, Int. J Coal Geology, 123 (2014)], and represents the gas release from deep zones of organic inclusions (kerogen) due to the diffusion of dissolved methane through the amorphous organic matter towards pore network. Although this diffusion is very slow, the small sizes of organic inclusions determine the finite time of gas release. In contrast to the superficial desorption of gas, which is an instantaneous process, the deep gas desorption introduces a significant delay, or memory, in the macroscopic behaviour of the system.

The appearance of the memory is the second new effect typical for shale, which is caused by its multiscale structure. The memory appears in all the types of mass transfers (not only in deep desorption) between the scales due to highly different flow rates characterizing various scales. Consequently, the mass transfer terms in conservation equations become integro-differential.

The mathematical model for such a process has been obtained by reiterated homogenization. For multiscale medium, the memory accumulation on different scales leads to the appearance of super-memory (the kernel of the integral operator is the solution of another integral equation on lower scale). For finite number of scales, the macroscopic model represents a recurrent system of integro-differential equations.

In the limit of infinite number of scales, this system can be split and reduced to a closed non-recurrent model of two integro-differential equations, in which the effect of super-memory leads to the appearance of a nonlinearity. By numerical simulations we have shown that this limit model describes well heterogeneous media with three-four and more scales.