A New Approach to Modeling Immiscible Two-phase Flow in Porous Media

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Introduction

Forced water-oil displacement and spontaneous countercurrent imbibitions are the two major mechanisms of secondary oil recovery. Modeling immiscible two-phase flow in porous media is of great importance in Reservoir Engineering.

In this work we present a new approach to modeling immiscible two-phase flow in porous media, in which mesoscopic fluids' interfaces are highly controlled by the injected interfacial energy, interfacial tension and the specific fluids' interface.

Challenges

✓Totally new approach through the perspective of energy balance instead of merely momentum and mass conservation

✓Realization with mesoscopic Cellular Automata (CA), each node of which represents numerous pores and solids

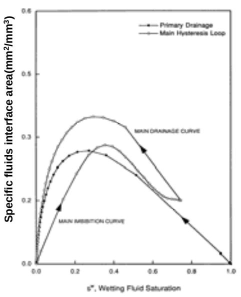
✓Describing the movements of dispersed mesoscopic fluids' interfaces

Theory

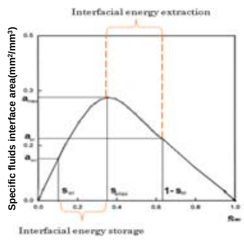
✓Injected energy during a waterflooding process turns into the frictional heat, and the interfacial energy.

✓Specific fluids' interface indicates the internal phase distribution in the porous structure and is dependent on the saturation in different processes.

✓Repetitive interface field forms due to heterogeneity: at low saturation the number of interfaces increases, at high saturation the number of interfaces decreases.



Simulation result based on pore network model[1]

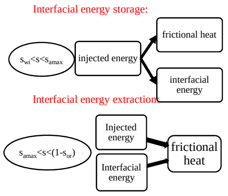


$$E_{storage\ capacity} = V\sigma(a_{max} - a_{wi})$$

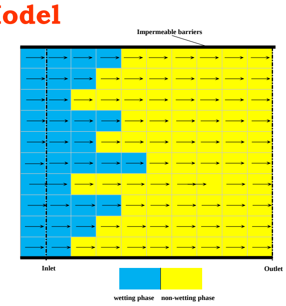
$$E_{max,extraction} = V\sigma(a_{max} - a_{or})$$

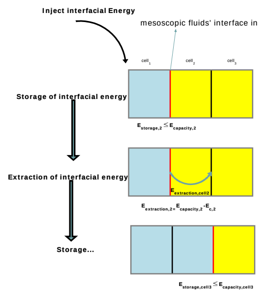
$$E_c = V\sigma(a_{or} - a_{wi})$$

Repetitive Meniscus Field: Purple lines: the displacing phase; the black points are the mobile menisci. Panfilov and Panfilova's network simulation[2].



Model

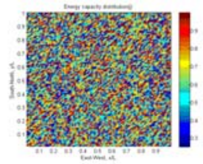


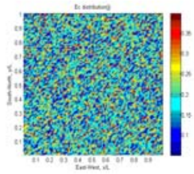


Main Assumptions:

1. The relation between specific interface and saturation is valid for any volume of porous medium, any cell in the CA, or the entire system.
2. A mesoscopic repetitive interface field forms during waterflooding (highly dispersed interfaces).
3. Any mesoscopic fluids' interface will never move forward to the neighboring cell until its stored interfacial energy exceeds the energy capacity of its cell. Extraction is assumed to be instant.
4. Injected interfacial energy in portions randomly walk till it meets an mesoscopic fluids' interface. Constant injection rate.
5. Simple CA system that only allow single-direction is adopted. Discrete time, discrete space, one set of transition rule. This assumption is not able to generate a repetitive interface field, and will be altered.

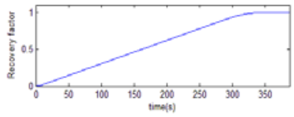
Randomly generated heterogeneous porous media:



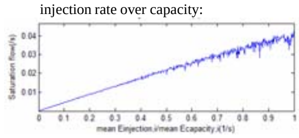


Results

Evolution of recovery factor: constant flow:

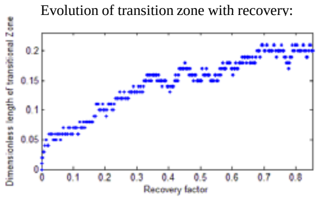


Flow increases linearly with the ratio of injection rate over capacity:

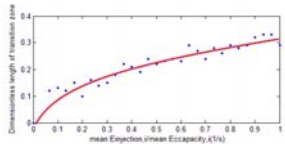


✓ Saturation flow is defined as the rate of recovery factor change

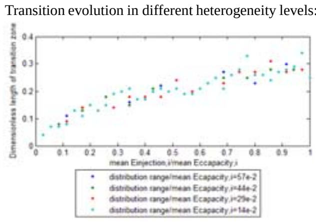
Evolution of transition zone with recoverv:



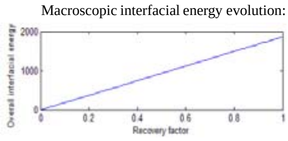
Transition zone increases with the ratio of injection rate over capacity:



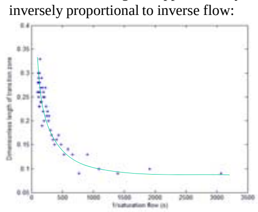
Transition evolution in different heterogeneity levels:



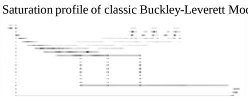
Macroscopic interfacial energy evolution:



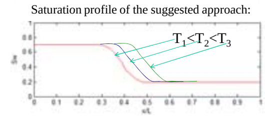
Transition zone length is approximately inversely proportional to inverse flow:



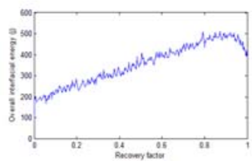
Saturation profile of classic Buckley-Leverett Model:



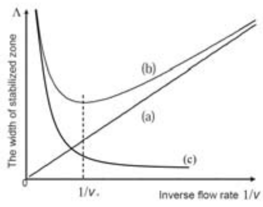
Saturation profile of the suggested approach:



Macroscopic interfacial energy with pseudo capacity:



✓ To overcome the problem of much too simple CA, a pseudo energy capacity is introduced, it is the amplified energy capacity to supplement the number of interfaces. The disappearing peak shows up again.



Rapoport-Leas model: (a), Barenblatt's non-equilibrium model: (b)[3], Suggested approach:(c).

Conclusions

✓ Approach through the perspective of energy balance is possible.

✓ Different from other models.

✓ More advanced CA system is required.

Reference

1. Reeves, P.C. and M.A. Celia, A Functional Relationship Between Capillary Pressure, Saturation, and Interfacial Area as Revealed by a Pore-Scale Network Model. Water Resources Research, 1996. 32(8): p. 2345-2358.
2. Panfilov, M. and I. Panfilova, Phenomenological Meniscus Model for Two-Phase Flows in Porous Media. Transport in Porous Media, 2005. 58(1): p. 87-119.
3. Barenblatt, G.I., T.W. Patzek, and D.B. Silin, The Mathematical Model of Nonequilibrium Effects in Water-Oil Displacement. SPE Journal, 2003. 8(4): p. 409-416.