A new methodology for effective, two-phase flow characterization of pore network structures

Marios S. Valavanides

Department of Civil Engineering, Applied Mechanics Laboratory

TEI Athens, Ag. Spyridonos, GR-12210 Athens, Greece

e-mail: marval@teiath.gr , web page: http://users.teiath.gr/marval/index_en.html

Key words: relative permeabilities, operational efficiency, network characterization

ABSTRACT

The non-linear behaviour of two-phase flow in porous media, even in steady-state conditions is attributed to the interplay between capillarity and bulk viscosity. Capillarity regulates the flow for “relatively low” Ca values, whereas, for “relatively high” Ca values, the flow configuration is dictated -predominantly through saturation- by the bulk viscosities of the two phases. Since the actual independent variables of the process are the water capillary number, Ca, and the oil/water flowrate ratio, r, the flow configuration (capillary/viscous) depends on the flowrates of the two phases. The oil/water viscosity ratio, κ, regulates the flow range conditions for the transition from capillary to viscous dominated configurations.

A new methodology is proposed for the normative characterization of two-phase flows in porous media as capillary or viscous. Conceptually, it is based on the existence of a locus, r*(Ca), on which optimum operation flow conditions (OOC) are met and process operational efficiency [reduced flowrate of oil per kW dissipated within the system, f_{EU}(Ca,r)], is maximized, Fig.1, [1,2,3]. In general, r*(Ca) is inversely proportional to Ca, and it can be approximated by a scaling function containing the oil/water viscosity ratio, κ, and two real, positive parameters A & B, eqn(1), Fig 2(a). The latter can be estimated from a set of laboratory determined optima for any particular oil-water-p.m. system. In addition, for any p.m. the various r*(Ca;κ) corresponding to pairs of fluids with different viscosity ratios but same wetting, when appropriately scaled, collapse into a single function, R*(Ca), eqn(2), Fig.1(b).

I) Flow characterization. In any r*(Ca) or R*(Ca) diagram, the OOC locus plotted on a log-log scale, shows a significant mutation as Ca is increased from “small” to “large” values: the combined effect of viscosity and capillarity turns from capillary dominated to capillary/viscous to viscous dominated. A critical value of the capillary number, Ca_{cv}, segregating capillarity- from viscosity- dominated flows can be determined and detected at the maximum curvature of the OOC locus, 1/ρ.

II) Pore network characterization. The interplay between capillarity and viscosity, is expressed by the particular form of the normalized OOC locus described by values {A,B} associated with the particular pore network structure and wetting conditions. Therefore, in addition to flow characterization, the particular form of the normalized OOC locus can also be used to characterize the structure of a pore network. Parameters A & B, record the overall effect of the network structure across a variety of flow conditions /systems. Any locally maximum value of operational efficiency, depends on the total mechanical power dissipation that, in turn, depends on the structure of the porous network i.e. not only on absolute permeability, but also on tortuosity, pore size distributions and correlations, micro-roughness, fractal characteristics, heterogeneities etc. In this context, the pore network structure can be characterized by evaluating the indices A & B, universally representing its effect (“footprint”) on flow configurations spanning viscosity to capillarity dominated flow regimes. The proposed methodology is conceptually equivalent to mercury porosimetry.

$$r^*(Ca) = \frac{1}{\sqrt{\kappa}} + \frac{A}{Ca^B}\ , \qquad A,B>0 \tag{1}$$

$$R^*(Ca) = 1 + \frac{A}{Ca^B}\ , \qquad A,B>0 \tag{2}$$

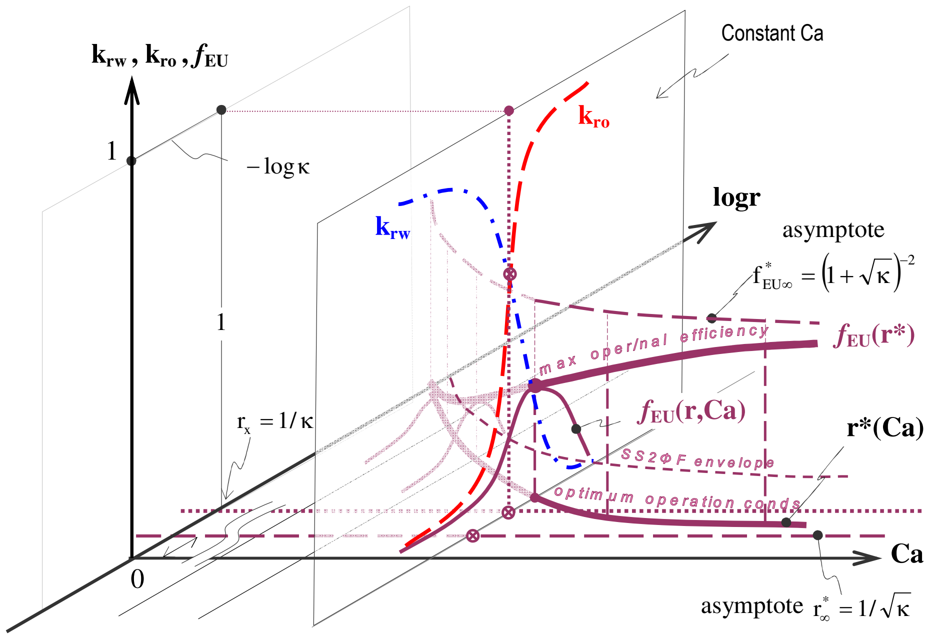
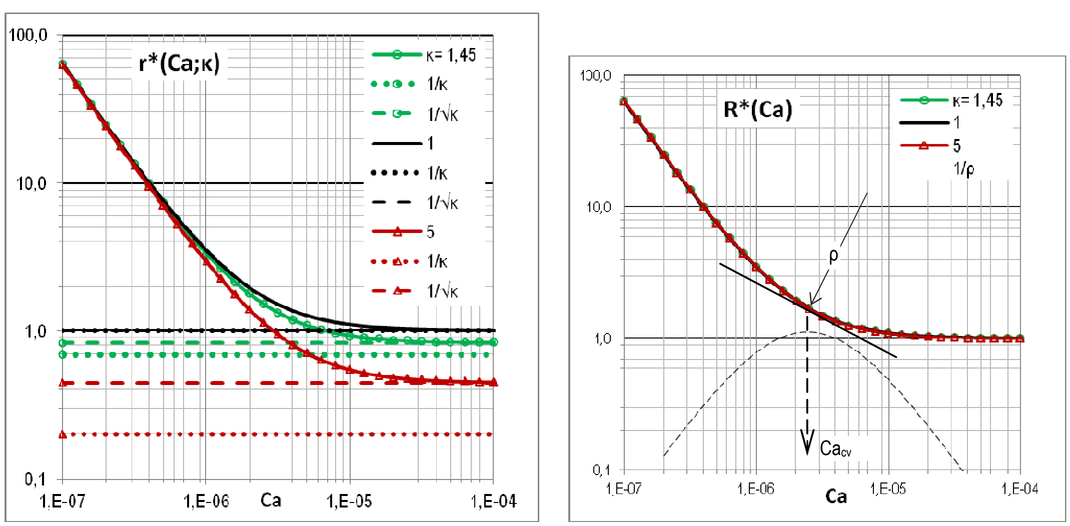


Figure 1 Universal, operational efficiency map for steady-state two-phase flow in porous media (impression for favorable viscosity ratio, $0 < \kappa < 1$). Note: r is on log scale, Ca on linear scale.



(a) (b)

Figure 2 Typical plots of the locus of optimum operating conditions pertaining to favourable ($0 < \kappa < 1$), indifferent (unity, $\kappa = 1$) and unfavourable ($1 < \kappa$) viscosity ratios. All loci share the same values for A & B. **(a)** Plots of $r^*(Ca;\kappa)$ are drawn using eqn(1), A=10^{-8}, B=1,4 **(b)** The plots in (a) collapse into a single plot, $R^*(Ca)$, eqn (2).

REFERENCES

[1] Valavanides, M.S., Totaj, E., Tsokopoulos, M. (2015) "Energy Efficiency Characteristics in Steady-State Relative Permeability Diagrams of Two-Phase Flow in Porous Media" *Journal of Petroleum Science and Engineering* PETROL6936R3, in press, pp. 1-34 http://users.teiath.gr/marval/publ/Valavanides_etal_JPSE_PETROL6936R3_2015.pdf

[2] Valavanides, M.S. (2014) "Operational Efficiency Map and Flow Characterization for Steady-State Two-Phase Flows in Porous Media" Society of Core Analysts Symposium - SCA2014-047, Avignon, France, September 8-14 http://users.teiath.gr/marval/publ/Valavanides_SCA2014-047.pdf

[3] Valavanides, M.S. (2016) "Universal operational efficiency map for immiscible steady-state two-phase flow in porous media processes. Introduction of a new methodology for process (flow and system) characterization." Working Paper *International Journal of Multiphase Flow,* http://users.teiath.gr/marval/publ/Valavanides_IJMF_2016.pdf