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Poiseuillean viscous flows in menisci–bounded "bridges"and crevices of triangular pore channels: Blunt's model revisited

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We consider Blunt's [1] pore as a straight cylindrical conduit of a triangular cross-section OO1O2. A viscous liquid bridge is bounded by menisci AMD and CNB which are assumed to be circular arcs of radii, r1 and r2, only slightly varying in the f-direction perpendicular to Fig.1a.

Fig.1
The contact angle ⊠⊠⊠/2. Flow in the f-direction (Fig.1b) is caused by the longitudinal gradient of pressure, p, in the bridge (like in [3]). This gradient emerges due to, for instance, increase of the disjoining and capillary pressure inside the liquid due to gradual "thinning"of the bridge (owing to, say, decrease of r2 and increase of r1¬). In application to evaporation of water in vertical isothermic porous columns (vadoze zone above a horizontal water table), the evaporation-induced "thinning"of the bridge is determined by a higher evaporation rate from the menisci of larger diameters (near the water table), as compared with the drier soil surface where the moisture content in desert sands is small and, therefore, the sizes of the water-filled crevices and menisci radii are tiny. We introduce Cartesian coordinates and get the Poisson equation:
. (1)
where u is velocity in the f-direction, ⊠⊠is the liquid's viscosity and e = const. The flow domain, Gz, in Fig.1c is made of two straight segments DC and BA and two arcs AMD and CND. The boundary conditions are:
(2)
where is an angular coordinate counted from the axis of symmetry of the bridge, i.e. OMN. The air phase is of zero viscosity. BVP (1), (2) is solved by the methods of complex analysis [2,3]. From this solution we get the vector filed u, flow rate through the bridge, Q(a,e,r_1,r_2)=∫_(G_z)⊠〖u(x,y)"d" s〗, and permeability of various bundles of triangular capillaries laden with bridges.

Fig.2
We also consider a right triangular conduit with an immobile air entrapped near the three vertices (O, O1,O2) in Fig.2a. Three identical menisci there are circular arcs of a constant radius r1; Gz is a circular sextagon bounded by these menisci and three no-slip segments. We consider a curvilinear pentagon Dz =ADECEEB, where E is the centre of the pore and EC and EB are the midpoints of the sides OO1 and OO2. Along EC EEB the shear stress is zero. If r1 is small enough (soil is close to full saturation), then the corner EC EEB of the pentagon is approximated by a circular arc. One circular arc of a radius r2m can be drawn via points EC and EB and another, of a radius r2M –via point E (Fig.2a, dotted line) that gives two domains, Dm and DM. These two bounding tetragons geometrically sandwich the curvilinear pentagon Dz. Hence, the maximum principle for Poisson's equation (1), yields a double inequality Qm < Qz <QM. Therefore, our analytical solution to BVP (1), (2) also approximates one for Dz in the case of in Fig.2a. Similarly, a viscous gas flow along the core of a pore channel with an "entrapped"water in the three crevices (Fig.2b) is studied.

Time Block Preference

Time Block C (18:00-21:00 CET)

References

[1] Blunt, M. J. (2017). Multiphase Flow in Permeable Media: A Pore-scale Perspective. Cambridge University Press.

[2] Gakhov, F. D. (1997). Boundary Value Problems. Nauka, Moscow (in Russian). (English translation of the 1-st edition, Addison Wesley, New York, 1966).

[3] Kacimov, A.R., Maklakov, D.V., Kayumov, I.R., and Al-Futaisi, A. (2017). Free surface flow in a microfluidic corner and in an unconfined aquifer with accretion: the Signorini and Saint-Venant analytical techniques revisited. Transport in Porous Media, 116(1), 115-142.

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