Colloids and Surfaces A: Physicochem. Eng. Aspects 461 (2014) 323–335

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

journal homepage: www.elsevier.com/locate/colsurfa

Modeling air–water interface in disordered fibrous media with heterogeneous wettabilities

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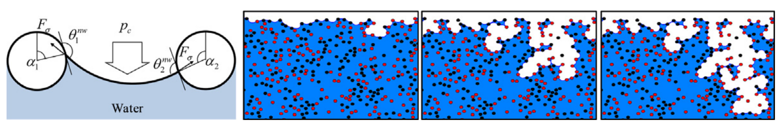
HIGHLIGHTS

- A model for tracking a fluid interface in a bank of parallel dissimilar cylinders.
- Algorithm is based on balance of applied pressure and capillary forces on menisci.
- Instantaneous interface shape and fluid saturation are obtained and reported.
- Algorithm can handle systems with fibers of multiple wettabilities.
- Proposed an equation to expand utility of results beyond the current simulations.

GRAPHICAL ABSTRACT

A novel interface tracking algorithm is presented which determines the location and shape of the fluid interface(s) over varying applied pressures for structures comprised of randomly placed parallel fibers or cylinders. Fibers of different hydrophilicities can exist within the same structure.



ARTICLE INFO

Article history:
Received 13 July 2014
Received in revised form 6 August 2014
Accepted 8 August 2014
Available online 19 August 2014

Keywords:
Capillarity
Fibrous media
Contact angles
Dissimilar fibers
Wettability

ABSTRACT

Considering the balance of mechanical forces across a meniscus anchored to two circular objects, we developed a CPU-friendly semi-analytical algorithm for tracking the instantaneous shape and position of the air–water interface inside microstructures that resemble a collection of disordered parallel cylinders, e.g., a bundle of fibers in a fiber-reinforced composite or microfabricated posts in a microfluidic system. In the context of fluid transport in fibrous media, in particular, the methodology presented in this paper provides a means for producing a relationship between capillary pressure and fluid saturation in media with heterogeneous wettabilities – often needed to predict the rate of fluid transport. In addition, we developed a conversion formulation that allows a capillary pressure–saturation relationship obtained for one combination of contact angles to be used to construct such a relationship for media with different combinations of contact angles, eliminating the need for additional simulations.

1. Introduction

Capillarity is the driving force that plays an important role in the displacement of one fluid by another at the microscale on a solid wall. Understanding and quantifying capillary forces is crucial in designing products and applications that deal with immiscible fluids. For instance, superhydrophobic surfaces utilize capillarity to repel water, making them suitable for self-cleaning purposes, as well as submerged applications benefiting from drag-force reduction [1,2]. In microfluidics, microposts can be added to thin flat microchannels to direct and control fluid transport and storage in microchannels and substrates (e.g., [3–5]). Quantifying capillarity is also essential in designing the gas diffusion layer (GDL) for polymer electrolyte membrane (PEM) fuel cells. Numerous recent studies have revealed the importance of the GDL's fibrous microstructure

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http://dx.doi.org/10.1016/j.colsurfa.2014.08.006
0927-7757/