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Effects of hydrostatic pressure on wetted area of submerged superhydrophobic granular coatings. Part 1: mono-dispersed coatings

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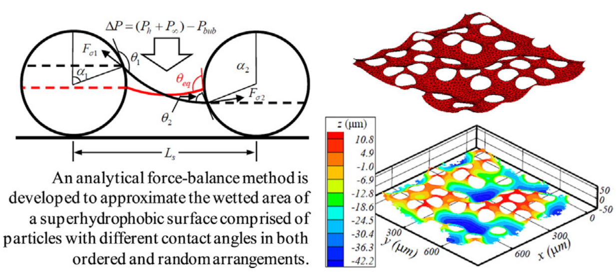
HIGHLIGHTS

- A new model is developed to predict the wetted area of a superhydrophobic surface.
- Wetted area is important for calculating the drag force on a submerged surface.
- The proposed method estimates drag force in terms of operating pressure.
- The proposed method is analytical, easy to use, and relatively accurate.
- The method extends to granular surfaces with random roughness.

GRAPHICAL ABSTRACT



An analytical force-balance method is developed to approximate the wetted area of a superhydrophobic surface comprised of particles with different contact angles in both ordered and random arrangements.

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ABSTRACT

Properly designed superhydrophobic surfaces can reduce the skin-friction drag on objects submerged in moving water. This drag reduction is caused by a reduction in wetted area from air entrapped in the pores of the surface. For granular superhydrophobic surfaces, where the air–water interface is not necessarily pinned to the pore entrance, predicting the wetted area is not a trivial task, as the air–water interface can easily move into or out of the pore in response to instantaneous operating pressure or due to air dissolution into the ambient water. The relationship between wetted area and drag-reduction is complicated, and reducing the wetted area does not guarantee a reduction in drag force. However, the ability to predict the wetted area allows one to design more efficient superhydrophobic coatings to meet the specific needs of different applications. This work presents an analytical force-balance method developed to approximate the wetted area of a superhydrophobic surface made of particles of equal size but different Young–Laplace contact angles. The accuracy of our simple analytical formulations is examined using the rigorous numerical calculations of the Surface Evolver code, and reasonable agreement has been observed. Effects of particle diameter, particle contact angles, particle packing fraction, and spatial distribution on positive and negative critical hydrostatic pressures and their corresponding wetted area are predicted and discussed in detail.

1. Introduction

The self-cleaning properties of Lotus leaves have motivated many studies in the past decade to investigate the so-called superhydrophobicity effect – a phenomenon which may arise from combining hydrophobicity with roughness [1–4]. Superhydrophobic (SHP) surfaces are often produced by imprinting micro- or nano-scale structures on a hydrophobic substrate or by

Abbreviations: AWI, air–water interface; CCP, critical capillary pressure; CHP, critical hydrostatic pressure; COPD, coating with ordered particle distribution; CRPD, coating with random particle distribution; FB, force balance; SE, Surface Evolver; SHP, superhydrophobic; SVF, solid volume fraction; YLCA, Young–Laplace contact angle.

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