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The characterization of wettability of substrates by liquid nanodrops

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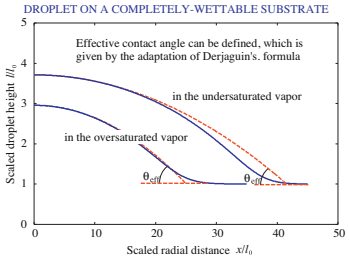
HIGHLIGHTS

- Droplet on a flat substrate.
- Droplet on a completely wettable substrate.
- Effective contact angle by generalized Derjaguin formula.

GRAPHICAL ABSTRACT



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ABSTRACT

Wettability of substrates is characterized by a contact angle. Applicability of the simple formula developed by Derjaguin, which relates to the contact angle and disjoining pressure to nano-scale liquid droplets is reconsidered within the framework of the theory of the first-order wetting transition of volatile liquids. It is concluded that his formula is generally correct for large droplets on an incompletely-wettable substrate. But it cannot be applied to nanodroplets, in particular, on a completely-wettable substrate. An effective contact angle can be defined even for the nanodroplet. A formula similar to the Derjaguin formula is proposed by which we can calculate the contact angle of nanodoroplets on both an incompletely- and a completely-wettable substrate for which the whole volume of the droplet is under the influence of the disjoining pressure.

1. Introduction

The contact angle, which Young [1] simply called angle, plays a fundamental role in various fields of surface science. It has been used to characterize the wetting properties of various surfaces. Materials deposited on a flat substrate form a hemispherical droplet shown in Fig. 1 and it is characterized by the radius R_{eff} and the apparent contact angle θ_a by which we can tell that the material can wet or not wet the substrate. Of course, Fig. 1 is idealized picture and there is a transition region between the bulk droplet and the thin liquid film. The information about wettability extracted from the contact angle can then be used to design useful new artificial surfaces and materials. Even though, the contact angle has been used for many years to characterize the surface experimentally or empirically, a reliable theoretical method which can predict the contact angle has still not been well developed.

Derjaguin [2], more than three decades ago, proposed a formula which relates to the contact angle and the disjoining pressure. Although, this formula opened a way to predict the contact angle and, therefore, wettability from the information of the disjoining pressure provided theoretically [3,4] or experimentally [5,6], its utility is not well recognized [7,8]. Also, several variants of derivation [9,10] of the original Derjaguin formula [2] have been proposed. However, due to the recent advances in nano-science and nano-technology, the contact angle of the nano-scale droplet becomes measurable using an atomic force microscope (AFM) [11] and environmental scanning electron microscopy (ESEM) [12]. In contrast, usual optical microscopy can only measure the contact angle of the milli-scale to micro-scale droplet.

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