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Description of the bubble shape on a planar solid surface with variable inclination angle

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Abstract

The bubble-particle interaction is a common phenomenon used in numerous industrial applications. A stable attachment of the bubble on a hydrophobic surface is influenced by fast and stable creation of the three-phase contact line. All mathematical models which describe the TPC line expansion utilize the knowledge of dynamic and equilibrium contact angles. The description of a drop or a bubble placed on an inclined plane or curved surface is very complicated. Up to now few methods were published, but these methods are not suitable for the description of sizeable amount of data. Therefore, the aim of this project is to figure out the methodology for relatively simple and fast calculations of contact angles. The special attention was paid on the ability of the model to describe the bubble shape during the adhesion on hydrophobic solid surface.When compared with the liquid drop placed on an inclined plane, the bubble holds nearly a spherical shape and contact angles in the upper and lower bubble end differ only little. The basic idea of our method is to divide the bubble into two parts and describe these parts separately. A set of points around the bubble is obtained and then the ADSA methodology is used. The calculated data were compared with experimental data and a very good agreement was obtained. The variation number divided by number of points corresponds to the value of experimental error. According to the obtained results it is possible to conclude, that during the bubble adhesion on slightly inclined plane the dynamic contact angle differ insignificantly and along the whole contact line contact angles could be described using the average value. The error of such approximation does not exceed the experimental error. In the first part of bubble adhesion, the value of dynamic contact angle is influenced primarily by the bubble size and the contact angle decreases with increasing bubble size. Results of the work could have a great importance in the study of bubble-particles interactions on non-horizontal planes. We assume a noticeable simplification of the calculation of the TPC expansion.

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1. Introduction

The bubble-particle interaction is a common phenomenon used in numerous industrial applications. One of the most important processes is the flotation. This classic method for the separation of mineral ores or coal is based on a process where large bubbles interact with small particles with hydrophobic surface [1]. A basic principle of a flotation method was applied also in another industrial branch - in the separation of plastics, but this separation is based on interactions of small bubbles and large particles. This contribution is focused on an interaction (an adhesion) between a small bubble and a large stationary particle, namely on the bubble adhesion. The adhesion is the 2nd step of the bubble-particle interaction and follows the collision between the bubble and the particle[2]. Main attention in our project is focused on study of the three-phase contact line expansion.

The three-phase contact line is created after the drainage of the liquid film after the bubble-particle collision. Here short-range forces take over the control, namely the interfacial tension, intermolecular forces (van der Waals forces), electrostatic interactions and steric forces (if surfactants are present in the system) [3]. The expansion of the TPC line is very fast for first few milliseconds. Finally the TPC line expands to the steady state where all forces are in the equilibrium. The equilibrium state and simultaneously the shape of the droplet is determined by the Young's relation [4]:

$$0 = \sigma_{sg} - \sigma_{ls} - \sigma \cos \theta_0 \tag{1}$$

The contact angle is the angle at which a liquid vapour interface meets the solid surface. Here, the solid-vapour interfacial energy is denoted as σ_{sg}, the solid-liquid interfacial energy as σ_{sl} and the liquid-vapour energy as σ. θ_0 is the equilibrium contact angle. The Young's equation assumes a perfectly flat surface, equilibrium between vapour and liquid phase and further ideal conditions. These requirements are usually not fulfilled, nevertheless this equation is widely used with sufficient accuracy in many applications.

The adhesion process can be measured using several methods - the dropping particle technique, the captive bubble technique and the freely rising bubble technique. The third mentioned method was chosen for our experiments. A small bubble rises in pure water to a solid particle represented by an inclined plane and a profile of the bubble is captured using high-speed digital camera. The three-phase contact line expansion can be described experimentally or theoretically [5]. From the theoretical point of view two mathematical models can be used: hydrodynamic and molecular-kinetic model. Both models express the radius of the TPC as a function of the dynamic contact angle, the equilibrium contact angle, time and one or two adjustable parameters. The key quantity is the dynamic contact angle and its dependence on time. Numerous methodologies have been developed for the measurement of interfacial tensions and contact angles. Of these, axisymmetric drop shape analysis (ADSA) methods are considered to be the most powerful because of their accuracy, simplicity and versatility. Unfortunately the description of a drop or a bubble placed on an inclined plane or curved surface is undoubtedly more complicated. Up to now few methods were published, but these method are not suitable for the description of sizeable amount of data. Therefore, the aim of this project is to figure out the methodology for relatively simple and fast calculations of contact angles. The special attention was paid on the ability of the model to describe the bubble shape during adhesion on hydrophobic solid surface.