Study on Boundary Slip at the Solid-Liquid Interface of the Rough Surfaces Immersed in Liquids with Low Surface Tension

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Abstract

As micro/nano fluid systems are widely used in many fields, the types of liquid delivered in micro/nanotubes are no longer restricted to aqueous or electrolyte solutions, but also include oils with low surface tension such as alkanes and alcohols. The fluid drag at the solid-liquid interface of micro/nanotubes an affects the delivery efficiency of micro/nano fluid, is of scientific interest. The boundary slip at the solid-liquid interface is one of the main factors to reduce the drag of micro/nano fluid. However, theoretical and experimental studies on boundary slip mainly focus on the solid-water interface. For the solid-oil interface, studies focus on the flat oleophilic surfaces. Surface roughness can enhance real contact area and the degree of wettability of the solid surface. As the oils have low surface tension (< 50 mN/m) compared with that of water, roughness of the oleophobic/philic surfaces are generally larger than that of hydrophobic/philic surfaces. Surface roughness can affect the accuracy of measurement of the boundary slip at the solid-liquid interface based on the hydrodynamic force model of the flat surface. Mechanism of the effect of roughness on the boundary slip is not clear, and the effects of the electrical field and pH value on the boundary slip still require further study. Therefore, study on measurement of boundary slip on the rough surfaces, and measures the boundary slip at the solid-oil interface of rough surfaces, can contribute to Fig. out the factors affected the boundary slip on the rough surface and reveal its mechanism, which has important theoretical significance and practical value to reduce the fluid drag in the micro/nano tube and improve the delivery efficiency of liquids with low surface tension.

This paper presents a measurement method of effective boundary slip on the rough surfaces using contact-mode AFM, based on the established hydrodynamic force model between the colloidal AFM probe and the rough surface. The effective slip lengths are studied by analyzing the setup of the reference surface and detecting the hydrodynamic force on the sphere of the colloidal AFM probe. The measured intrinsic slip and effective slip lengths of the flat and rough surfaces immersed in hexadecane and ethylene glycol are obtained and compared. Results show that the effective slip lengths of the rough surfaces are smaller than that of the flat surfaces.

By improving preparation technique, composite layers coating with same degree of wettability and various amplitude/spacing roughness are prepared using nanoparticles and polymer binder. The effective length of samples immersed in hexadecane and ethylene glycol are studied respectively. State model of the solid-liquid interface on the rough surface is established via homogenization method, and is used to analyze the respectively effect of amplitude and spacing roughness on the effective boundary slip. The mechanism is diaacussed. Results show that the increasing amplitude roughness enhibites the effective slip length, and the effective slip lengths remain constant with the increasing spacing roughness.

The effect of surface charge on the effective slip length of the rough surface is studied with applied electrical field. The rough superoleophilic, oleophobic and super oleophobic samples and the flat PS and OTS samples are prepared using nanoparticles and binder. The effect of electric field intensity on the surface charge density and slip length of samples immersed in oils are studied. Results show that for the rough samples, the effective slip lengths of oils remain constant with the increasing voltage. For the flat surfaces, the increasing voltage leads to an increase in the slip length. As the equivalent capacitance determines the capability of charged surface, the effect of electric field on the characters of solid-liquid interface is related to the surface equivalent capacitance. The equivalent capacitance of the rough samples is smaller than that of flat samples. The surface charge at the solid-liquid interface affects the interaction between liquid and solid molecules and change the slip length. Results are consistent with the study by Joly that it has relationship between surface charge density and slip length.

The change of pH value can lead to the change of the surface charge at the oil-liquid interface. The Ethylene glycol and aqueous solution in the range of pH value from 3 to 11 are prepared respectively. The slip length and surface charge density of liquids with various pH value are studied. Results show that the surface charge density of ethylene glycol is much smaller than that of aqueous solution. In the range of pH value from 3 to 8, the slip lengths of ethylene glycol increase with the increasing pH values. In the range of pH value from 8 to 11, the slip lengths of ethylene glycol decrease with the increasing pH values. It can be explained by the absorbtion of negative ions in acidic or alkaline liquids lead to an increase of the surface charge density with various pH values. In the range of pH value from 3 to 11, the slip lengths in aqueous solution decrease with the increasing of pH values. It can explained by the existence of hydroxyl groups in water which affects the adsorption of negative ions on the surface under acidic environment, leading to a decrease of surface charge density.

In conclusion, this paper studies the measurement of the effective boundary slip length on the rough surface by establishing the hydrodynamic force model between the colloidal AFM probe and rough surface in the liquid environment. The effects of the amplitude and spacing roughness on the effective boundary slip are studied respectively. Then the effects of surface charge with applied electrical field and various pH values on the effective boundary slip were studied.

Key words: low surface tension, rough surface, solid-liquid interface, boundary slip, roughness, surface charge, Atomic Force Microscope