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# Forced wetting of stainless steel by distilled water drop

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**Abstract.** Experimental results analyses of macroscopic contact angle change from the drop growth rate of distilled water on stainless steel substrates is presented. The value of contact angle is found to depend on the drop growth rate ($m$): contact angle decreases at $m$ up to 0.02ml/s and increases at $m$ more than 0.02ml/s. At the final stage of spreading the contact line pinning occurs, depending on the drop growth rate and surface roughness.

## 1 Introduction

Theoretical, experimental research and modelling of the fundamental laws of heat and mass transfer processes [1-9] in multiphase systems are extremely important for the optimization of modern energy technologies. Nowadays irrigation technologies are paid full attention in the chemical, food, agricultural and other fields. It is connected with the reason of possible increase in the efficiency of production processes through the use of drop systems.

The spreading of a drop on a surface is known to depend on surface microstructure and properties of the liquid [10-16]. There is a lack in the experimental research studying the effect of the drop growth rate on the spreading.

The purpose of the work is to find experimentally the dependence of the macroscopic contact angle on the drop growth rate on microstructured surface of stainless steel substrate.

## 2 Experimental technique

Experimental studies were carried out by using the shadow and Schlieren optical methods. The scheme of the experimental setup is presented in Fig. 1 [11-13]. To implement the optical shadow method, the light source 1, ground glass 2, shield with an opening 3, and the collimating lens 4 were used to produce a beam of plane-parallel light illuminating a drop on the substrate 5.

The condensing lens 6 and camera lens 8 were used to project the image on the camera sensor. To implement the Schlieren method, source of incoherent light 17, ground glass 16, and condensing filter 15 were used to obtain the light flux with a stepwise decrease in

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intensity over the space. The light beam from the source 17 passed through the collimating lens 14, which transformed it into a plane-parallel. Then it reflected on the beam splitter 13, passed to the substrate 5 and then to the lens 12, focused on the filter 11 and projected onto the camera sensor 10 by the lens.

A drop was squeezed by a syringe electronic pump 9 from the bottom side of the substrate 5 through an 2 mm opening. The flow rate of distilled water was controlled in the experiment from 0.005 mL/sec to 0.16 mL/sec.

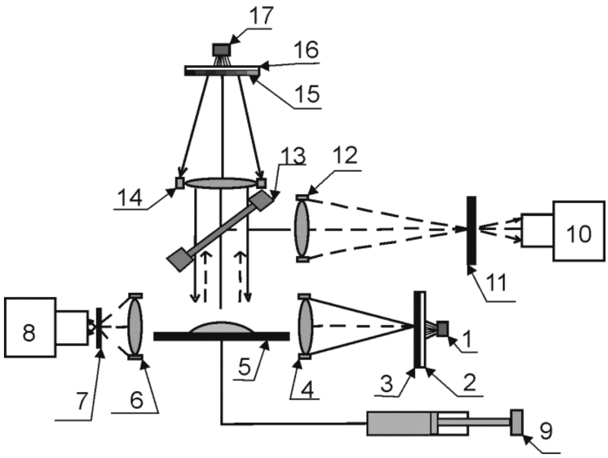


**Fig. 1.** Schematic diagram of an experimental setup: 1, 17 – light sources; 2, 16 – ground glasses; 3,7,11 - transparent shields with an opening; 4, 14 - collimating lenses; 5 – substrate; 6, 12 - condensing lenses; 8, 10 - high-speed video cameras; 9 – syringe pump; 13 - beam splitter; 15 - coding filter.

Three substrates made of stainless steel were used in the experiment. Their surfaces have different roughness: 1.5; 1,554; 4.59 µm. The photographic images of the substrates are shown in Fig.2.

(a) (b) (c)

**Fig. 2.** Photographic images of the substrates: (a) not bombarded by aluminum oxide particles; (b) bombarded by 10 µm aluminum oxide particles; (c) bombarded by 100 µm aluminum oxide particles

It is known the condition of wetting the material by liquid 90 °> $\theta$> of 0 °; the increase in the roughness causes a decrease in the macroscopic contact angle. In the absence of wetting $\theta$> 90 ° an increase in roughness increases the macroscopic contact angle.

Wenzel-Derjaguin equation does not consider the location of the cavities and asperities forming the roughness and the drop growth rate. The calculation the macroscopic contact angles with using thermodynamic equations is only possible if the surface roughness is formed by spaced parallel grooves. When the grooves are located chaotically, the values of angles may not be matched with the conclusions obtained from thermodynamic analysis. To date, there are no experimental data on the analysis of the influence of the microstructure (arrangement of the grooves on the surface) at different drop growth rate on the macroscopic contact angle.

## 3 Results and discussion

According to the experimental results (Table 1) the drop growth rate is found to affect the contact angle. It decreases with increasing flow rate (drop growth rate) reaching a minimum value at $m$=0.02 mL/sec. When values of flow rates are more than 0.02 mL/sec, the contact angle was observed to increase. It is worth noting that such dependence was obtained for surfaces with roughness formed both longitudinally and chaotically arranged grooves.

**Table 1.** Macroscopic contact angles.

| Substrate | Flow rate of distilled water (drop growth rate), mL/sec | | | | | |
|---|---|---|---|---|---|---|
| | 0.005 | 0.010 | 0.020 | 0.040 | 0.080 | 0.160 |
| Sample No 1 (Ra 1.500 μm) | 78° | 77° | 76° | 80° | 81° | 82° |
| Sample No 2 (Ra 1.554 μm) | 89° | 84° | 83° | 91° | 93° | 94° |
| Sample No 3 (Ra 4.590 μm) | 97° | 95° | 83° | 84° | 85° | 89° |

According to analyses of obtained angles (Table 1), the macroscopic angle is found to increase with an increase in the roughness when the drop growth rate is up to 0.02 mL/sec. The lower flow rates correspond to the larger values of the contact angle, and also its increase with an increase in the roughness.

The angle is found to be more than 90° ($\theta$> 90 °) on the surface with the roughness 4.590 μm and the liquid flow rate up to 0.01 mL/sec. It means dewetting condition. With increasing liquid flow rate up to 0.02 mL/sec $\theta$ varies between 90 °> $\theta$> 0 ° (liquid wets the surface).

The macroscopic contact angle increases with an increase in the roughness and at the drop growth rate more than 0.02 mL/sec. It is worth noting that the greatest values of $\theta$ are recorded on the substrate with Ra=1.554 μm (the roughness of substrate was formed by chaotically arranged cavities and asperities). Moreover, $\theta$> 90 °, which is characterized by the absence of wetting. The value of angle varies in the range of 90 °> $\theta$> 0 ° on the sample №3 at Ra = 4.590 μm (liquid wets the surface).

According to the analysis of experimental data (Table 1) obtained for samples No 2 and 3 (with the arithmetic average roughness 1.554 μm and 4.590 μm, respectively) it was found that when the cavities and asperities are arranged chaotically on the surface, the conclusions obtained on the basis of thermodynamic analysis of the Wenzel-Derjaguin equation do not agree with the experimental data.

Most likely this is due to the fact that the hydrophobic and hydrophilic properties are affected significantly, in addition to the roughness, the drop growth rate.

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