SPREADING BEHAVIOR OF A DISTILLED WATER DROP ON A SUPERHYDROPHOBIC SURFACE

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Introduction

Spreading of liquid drops on a solid substrate is general process in technology and nature. However, despite much research of interface in “solid-liquid-gas” system over many years, the precise nature of three phase contact line at the dynamic interaction of a drop with a solid surface remains only partially understood. It leads to inhibition of technology development at cooling surfaces [1], various coatings [2], ink jet printing [3, 4], spraying fuel in internal combustion engines [5] and etc.

Currently the study of superhydrophobic surfaces has a great interest because of their unique properties and various important applications. By a common definition, a surface is superhydrophobic if the contact angle (CA) of water is larger than 150° and water droplets readily slide off the surface if the surface is tilted slightly [6].

Applications of superhydrophobic surfaces include self-cleaning and non-wetting coatings and fabrics [7], as well as anti-fogging [8], anti-icing [9], and drag-reducing [10] coatings. A famous example of surface for superhydrophobicity from nature, the lotus leaf, has 10-micron papillae in combination with a nanostructure created by hydrophobic wax crystals.

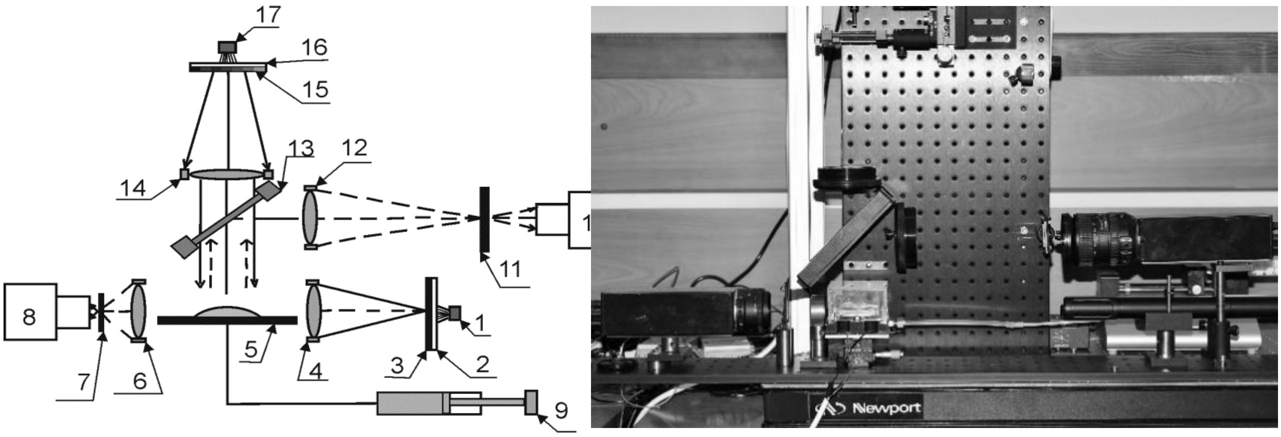
The process of water drop and solid substrate contacting is characterized by two main parameters: dynamic contact angle (DCA) and three-phase contact line velocity. Depending on the three-phase contact line velocity low-rate dynamic contact angles and high-rate dynamic contact angles are separated. Experimental investigation of the change of DCA during surface wetting by advancing and receding drops at slow movement of the three-phase contact line (from 0.002 to 0.09 mm/s) were conducted in [11-13]. However, wetting dynamics at high three-phase contact line velocity (greater than 1 mm/s) remains poorly explored. It is due to that the registration of physical mechanisms of fast processes become possible only in the last decade in connection with the improvement of photos and video equipment.

In this paper the results of investigating DCA at distilled water drop spreading on superhydrophobic surface are presented.

Research technique

The researches have been conducted using experimental setup shown in Fig. 1. It consists of equipment for realization of shadow and Schlieren methods [14]. The concept of research and operation are given in [14].

In shadow optical method the light source 1, ground glass 2, transparent shield with an opening 3 and lens 4 are used to produce a beam of plane-parallel light illuminating the drop on the substrate. The collimating lens 6 and objective of camera 8 are used to project the image on the camera sensor. Transparent shield with an opening 7 is set to reduce the effect of external light sources on measurement.



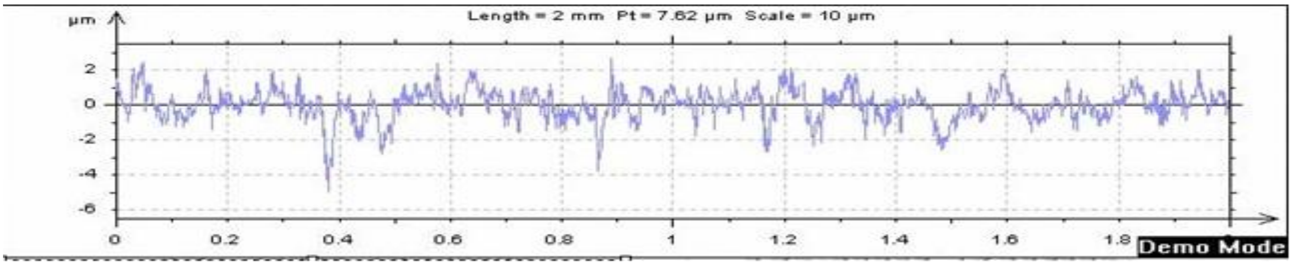
(a) (b)

Fig. 1. – Schematic diagram (a) and general view (b)
of the experimental setup:
1, 17 – light source; 2, 16– ground glass; 3, 7, 11 – transparent shield with an opening; 4, 14 – collimating lens; 5– substrate; 6 – condensing lens; 9 – syringe pump; 8, 10 – high-speed video camera; 12 – Schlieren lens; 13 – beam splitter; 15 – coding filter.

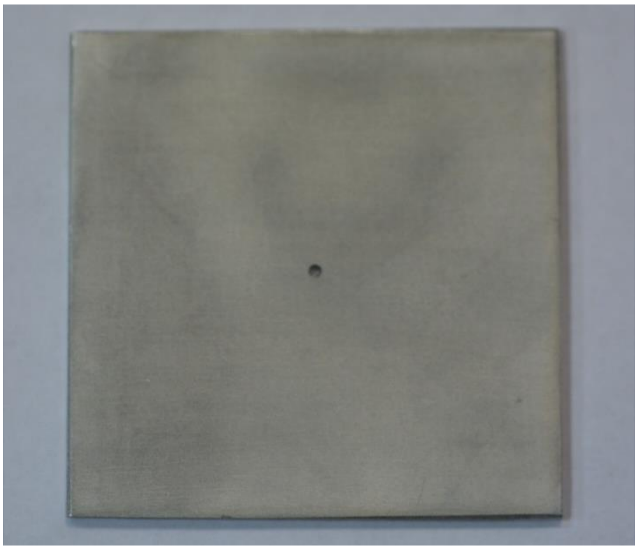
In Schlieren method the source of incoherent light 17, the ground glass 16 and the coding filter 15 are used to produce the light flux with a stepped decrease of intensity in space. A beam of light from the source 17 passed through the collimating lens 14, which transformed it into a plane-parallel. Then it was reflected from the beam splitter 13, fell to the substrate and passed to the lens 12 and projected on the sensor of the high-speed video camera 10.

Photographing and video recording of spreading droplets on the surface was carried out simultaneously in two coordinate directions. The equipment for realization of Schlieren method was used to control of the drop symmetry.The drop was formed on the surface by the syringe pump 9 (Cole-Parmer Touch Screen). The nondeaerated distilled water was squeezed on the surface through the channel placed in the substrate. This bottom-up methodology of droplet formation in comparison with the known syringe dispenser facilitates precise control of droplet formation and size as well as it allows reducing the error at maintaining the initial volume. The drop volume (0.3 ml) and the drop growth rate (from 0.005 ml/s to 0.32 ml/s with an increase of twice the value on each step) were controlled during the experiment.

The substrate with superhydrophobic surface was used in the drop spreading process. The substrate is a square thin plate (50x50mm) with the opening in the middle with diameter of 1 mm (figure 2 (a)) for liquid squeezing. Surface was investigated on the profilometer “Micro Measure 3D station”. The parameter of roughness (arithmetic average roughness Ra=0.751μm) was obtained. Surface profile is shown in Figure 2.



(b)



(a)

Figure 3. – The substrate with superhydrophobic surface: (a) – general view; (b) – surface profile.

Results and discussions

The dependence of DCA on the drop volume at different drop growth rate is shown in Figure 4.

The advancing DCA characterizes the degree of surface wettability at moving three-phase contact line (at increasing the contact area). According to the experimental results some features of spreading process on superhydrophobic surface was pointed out. During the formation of liquid drop firstly the "abrupt" increase of the three-phase contact line velocity and DCA occurs. Later spreading stage is detected which is attended by a decrease in three-phase contact line velocity and monotonic increase of the advancing DCA.

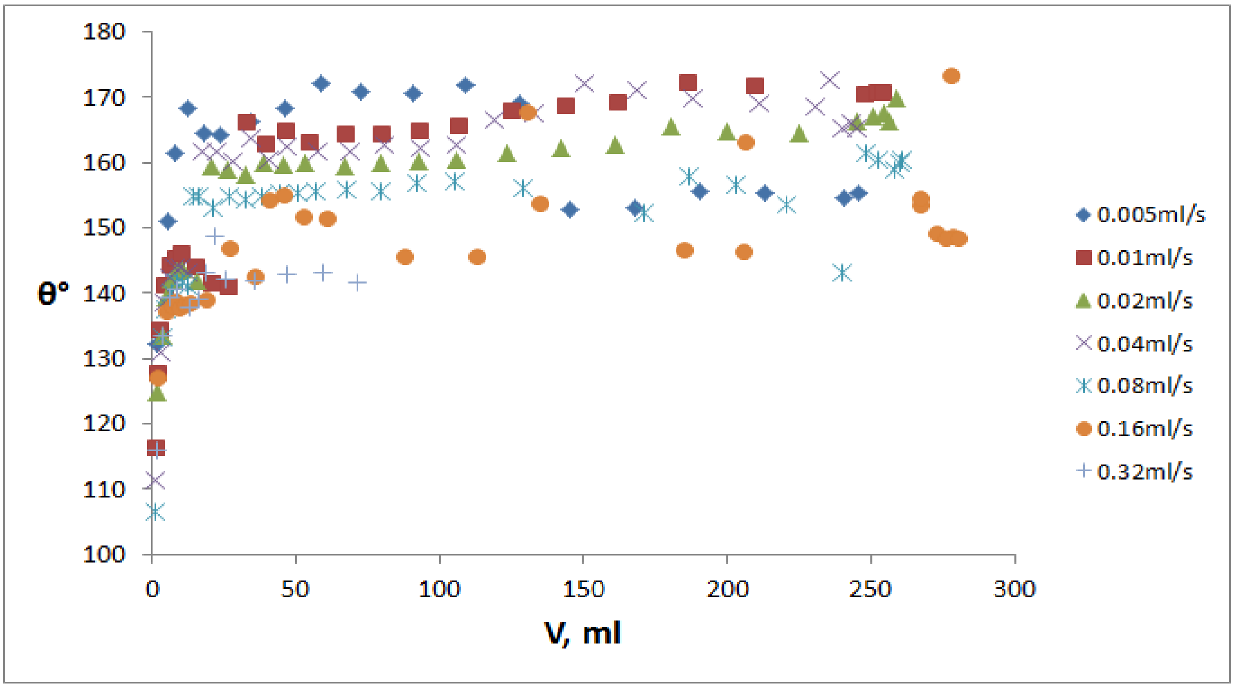


Figure 4. – DCA versus drop volume at different drop growth rate from 0.005ml/s to 0.32 ml/s.

At drop spreading on superhydrophobic surface the advancing DCA increases during all three stages (1 – drop formation; 2 – spreading; 3 – formation of the equilibrium contact angle [15]). The only exception is spreading at the drop growth rate 0.005ml/s.

Decreasing DCA is indicated during spreading and formation of the equilibrium contact angle stages Increasing DCA is the reason for that cohesive forces dominate over adhesive at the spreading of distilled water on non-wetting surface (in this case a superhydrophobic).

After turning off the syringe pump drop tends to assume an equilibrium state. Interfacial energy on the "solid – liquid" boundary seeks to squeeze a drop, notably the surface energy decreases due to the decrease in surface area. The cohesive forces acting inside the drop prevent spreading.

Within the range of the drop growth rate from 0.005ml/s to 0.16 ml/s the drop forms on the surface having a shape close to spherical cap. However, at the drop growth rate 0.32ml/s the drop was not received. It was observed significant liquid splashing (Figure 5).

The number of frame and time of spreading drop on superhydrophobic surface are presented under pictures (Figure 5). It is observed that after splashing liquid (t=0.523 second) water congregates back in drop.

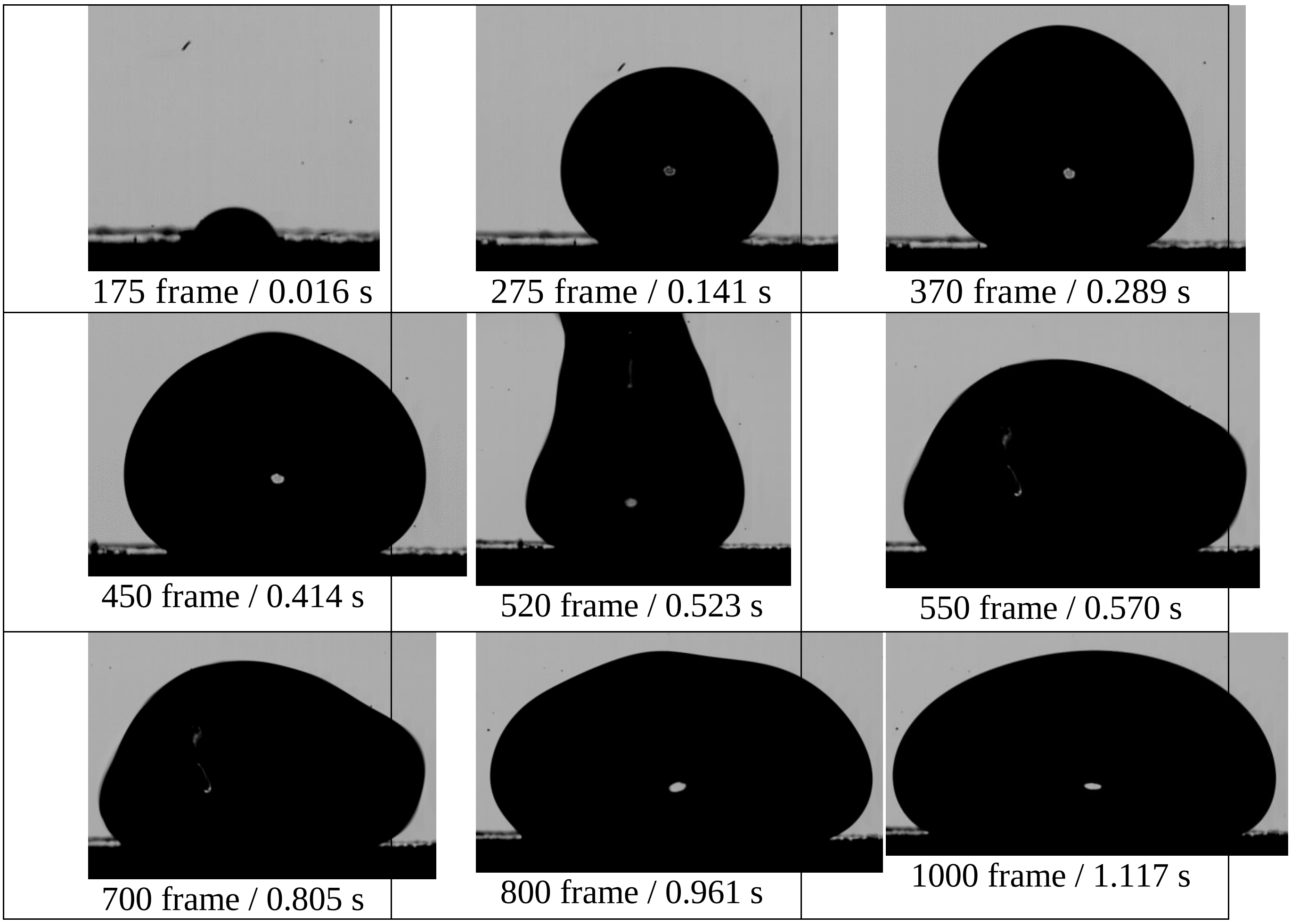


Figure 5. – Evolution of drop profile at the drop growth rate 0.32 ml/s.

Conclusion

1) The experimental setup and method for studying the distilled water drop formation during spreading process on solid horizontal superhydrophobic surface.

2) Advancing DCA of a liquid droplet was defined.

3) According to the experimental results some features of spreading process on superhydrophobic surface is pointed out.

a) The advancing DCA increases during all three stages (1 – drop formation; 2 – spreading; 3 – formation of the equilibrium contact angle).

b) The only exception is spreading at the drop growth rate 0.005ml/s, where DCA decreasing was found.

c) Within the range of the drop growth rate from 0.005ml/s to 0.16 ml/s the drop forms on the surface having a shape close to spherical cap. However, at the drop growth rate 0.32ml/s the drop was not received. It was observed significant liquid splashing.

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СОБИРАТЕЛЬНЫЙ ОБРАЗ ПРЕДСТАВИТЕЛЯ АМЕРИКАНСКОЙ КУЛЬТУРЫ ПОСРЕДСТВОМ ВЫДЕЛЕНИЯ ОСНОВНЫХ АМЕРИКАНСКИХ ЦЕННОСТЕЙ

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Анализ ценностей культуры американского народа представляет для нас большой интерес, так как мы имеем дело с анализом культуры, считающейся одной из ведущих сверхдержав и оказывающей существенное глобальное влияние. Стоит отметить, что ценности имеют большое значение при изучении любой культуры, поскольку они являются регуляторами деятельности индивида.

Тем не менее, герои и события многих кинолент воплощают те ценности, которые можно выделить в рамках культурологических исследований и считать чисто национальными.

К сожалению, существующие на сегодняшний день источники культурологических исследований расходятся как в количестве ценностей, так и в их приоритетном расположении. Исходя из этого, необходимо производить анализ ценностей, руководствуясь наличием тех или иных ценностей в списке как таковых, а не их приоритетным расположением. Представленные ниже ценности американского народа упоминаются в работах современных культурологов и имеют чисто национальный характер. Перечисленные ниже американские национальные ценности упоминаются в современных культурологических исследованиях как чисто национальные [2, с. 305].

1. Action/Work Orientation
2. Change
3. Competition
4. Directness/Openness
5. Equality
6. Future Orientation
7. Honesty
8. Individualism and Privacy