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A method for contact angle measurements under flow conditions

Andrzej Gajewski *

Department of Heat Engineering, Institute of Environmental Engineering and Protection, Bialystok Technical University, Wiejska 45E Street, 15-351 Bialystok, Poland

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Abstract

In this paper at first, a review of methods for measurements of the contact angle is presented. Following the review for contact angle measurements is developed method based on Langmuir approach. The method is aimed to be use in measurements the contact angle and rivulet's width under vertical flows as well as for the cases when rivulet does not flow down vertically along a vertical plane.

Keywords: Rivulet; Liquid film; Surface energy; Laser

1. Introduction

The wetting phenomena are present in many processes such as: heat and mass transfer under two phase flow, spray cooling, production of photographic films, washing, oiling engines, painting and many others. For a liquid flow there are two forms of wetting: the first is by the film, when a liquid covers the whole surface of solid phase. Hence, the contact angle is equal to zero. The second case refers to the rivulets, when only a part of solid surface is covered by a liquid and then the contact angle is greater than zero. Under such circumstances the value of contact angle is not only a function of macroscopic material properties of the solid phase, properties of the liquid flowing along it and properties of surrounding gas (or vapour) but also hydrodynamic phenomena and microscopic properties of solid surface, such as its roughness, as well as thickness and composition of surface-active subfilm. The contact angle is the macroscopic observed resultant of these phenomena and properties. From above discussion it appears, that the contact angle is affected by many factors, so measurement of contact angle for a liquid in flow must be very complex.

2. Experimental methods for contact angle measurements

The first experimental investigations of the contact angle for the sessile drop (under static conditions) were conducted by Langmuir and Schaefer [1] in thirties of the XXth century. They constructed the vertical protractor, where 0° corresponds the vertical line and 90° to the horizontal line, see in Fig. 1.

During the measurements the flashlight was held aside of the observer's head. If the angle of incident light

* Tel.: +48 85 7 46 96 90; fax: +48 85 7 46 95 76.
E-mail address: gajewski@pb.bialystok.pl

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Nomenclature

a	a measurement value
B	fixed error
d	diameter
h	height
i,j	natural numbers
l	distance
L	distance between laser and an edge of rivulet
w	rivulet width
x,y,z	coordinates

Greek symbols

α	angle
β	angle of laser rotation
γ	horizontal plane
δ	overall uncertainty
θ	contact angle
σ	standard deviation
ω	inclined plane

Subscripts

b	benchmark
l	laser beam
m	value determined as a result of measurements

at the drop was smaller than the contact angle θ then the starlight was observed. By increasing the angle of observation the condition, in which no light was seen, was achieved. Hence it meant that the observer was looking perpendicular to the tangent to the drop at the three-phase point. A pointer attached to the graduated scale was moved until it was in straight line from observer's eyes to the three-phase point. The contact angle's value was read off on the graduated scale θ_m. So the method is based on the looking for the normal to the curved surface. The precision of the method by Langmuir and Schaefer estimated to be 0.5°.

Towell and Rothfeld [2] in their research on the contact angle of rivulets used the idea of seeking for the normal to the surface. Because the rivulet flowed down the plate it was no way to measure the contact angle using a protractor, so they determined the contact angle θ by measurement the l_1 and l_2 distances, see in Fig. 2. Hence the contact angle is calculated from the formula

$$\theta = \mathrm{tg}\left(\frac{l_2}{l_1}\right). \quad (1)$$

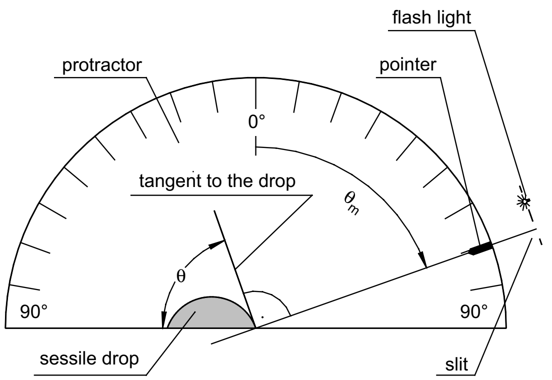

Fig. 1. Reconstruction of Langmuir method based on [1].

The method by Towell and Rothfeld [2] was modified by Semiczek-Szulc and Mikielewicz [3]. They used the laser beam, see in Fig. 3, instead of a lamp. In that case, the laser beam incidences at a selected edge of the rivulet and a fleck of light is observed on the screen after reflection. In turn, a quotient of distances l_2–l_1 equals the tangent of a double contact angle and hence, the maximum value of the contact angle must be less than 45°. The results of the experimental investigations for laminar rivulets driven by gravity are presented by Semiczek-Szulc and Mikielewicz in [3].

The Semiczek-Szulc and Mikielewicz method [3] was used for purposes of the present work in the first experiments. Because the scope of the experiments has been broadened beyond the laminar flow, the contact angles greater then 45° have needed to be measured. To increase the range of measurements a turned plate was used. Since the axis of rotation was set in a distance from the rivulet edge, the distance l_1 changes. As a measurement of the changing value l_1 is impossible (because

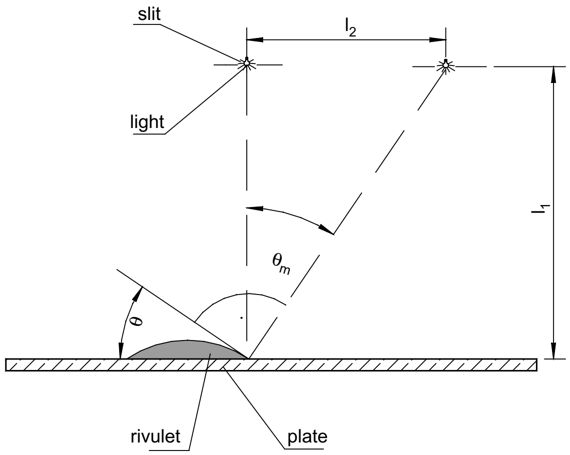

Fig. 2. Towell and Rothfeld method [2].