Equilibrium contact angle at boiling condition

Fabio Villa*[1,3], Marco Marengo[2,3], Joël De Coninck[1]
1University of Mons, Laboratory of Surface and Interfacial Physics (LPSI),19 avenue Maistriau, 7000 Mons, BE
2University of Brighton, School of Computing, Engineering and Mathematics, Lewes Road, BN2 4GJ Brighton, UK
3Università di Bergamo, Dipartimento di Ingegneria e Scienze Applicate, Viale Marconi 5, 24044 Dalmine, IT

Introduction

Let us consider a sessile droplet. If the temperature of the system is higher than the saturation temperature (T_{sat}) of the liquid the measurement of the equilibrium contact angle becomes very challenging measure with great implication for two-phase flows, boiling phenomena and evaporation processes. Furthermore the equilibrium contact angle close to boiling conditions is an essential input specification for numerical simulations capturing the heterogeneous phase change phenomena. In this paper, we report such experiments recording the evolution of the contact angle (CA) of a sessile drop on the heated surface using a high speed camera (HSC) and an infrared high speed camera (IRC). Several groups have studied the effect of temperature on the equilibrium contact angles experimentally, with direct measurement, or numerically, using molecular dynamic simulation. However there is some disagreement between the authors. The experiments seem to show a reduction of the equilibrium contact angle with the increase of the temperature, for hydrophilic surface. In Aydar et al. [1] contact angles of oils on polytetrafluoroethylene (PTFE) with different surface temperature were measured and compared to values predicted by Girifalco-Good-Fowkes-Young (GGFY) equation, that predicts a reduction of contact angle with increase of the temperature. For Petke et al. [2] also on hydrophobic surface the CA should decreases with temperature. Conversely Kandlikar et al. [3] measured the CA during rapid evaporation of liquid on a heated hydrophobic surface and the values of the contact angles for higher temperatures are remarkably constant. On the other hand, molecular dynamic simulations seem to indicate a reduction of the CA with temperature if the surface is hydrophilic and an increase of CA with temperature if the surface is hydrophobic (Becker et al. [4]). Our work focus on the measure of the equilibrium contact angle for sessile droplets on hydrophilic (Aluminium) and hydrophobic (PTFE) surfaces, measuring at the same time the temperature of the droplet and the temperature of the substrate, in order to clarify the influence of temperature on values of the contact angle for both surfaces. Three fluids are used, water, ethanol and isopropanol.

Material and methods

The apparatus used for the present investigation is schematically described in **Error! Reference source not found.**. The evaporation of the droplet is recorded by a high-speed camera (VDS Vosskuehler®). A heater (Heated Environmental Cell, Ramé-Hart ®) heats the sample up to the required temperature. The surface temperature is kept constant by a PID controller. A IR-camera (SC5000 Flir®) is placed on the other side of the chamber to measure the temperature of the liquid interface. Hence the IR-camera measures the temperature of the droplet before touching the sample surface and also the temperature evolution of the droplet interface during evaporation.

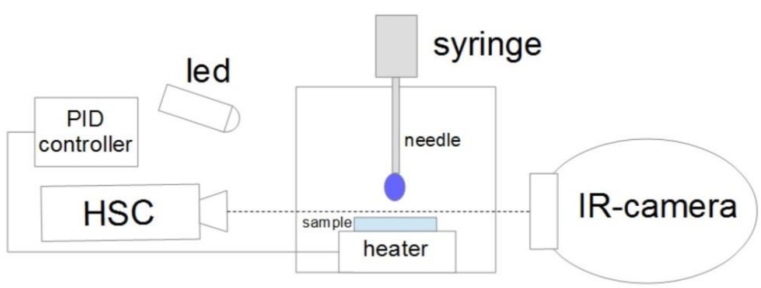

Figure 1: Sketch of the experimental set-up

In order to measure the equilibrium contact angles of the droplet, a specific post-processing routine has been developed within the general framework of Matlab© software. Table 1 reports the equilibrium contact angle (measured at ambient temperature of 17°C) for the two considered surfaces (Aluminium and PTFE). The surfaces can be considered smooth (R_a<0.2 µm).

Table 1. Equilibrium contact angle of the surfaces, measured with sessile drop method (liquid is water). The mean roughness (R_a) is also reported.

Surface	Equilibrium contact angle [°]	Ra [μm]
PTFE	106 ± 2	0.188
Aluminum	62 ± 2	0.135

Table 2 presents the physical properties of the tested liquids. Though the study is concentrated on water liquid behavior, also two other liquids (ethanol and isopropanol), with lower surface tension, are tested.

Table 2. Physical properties of the three liquids tested. T_{sat} is the boiling temperature (at 1 atm). Surface tension and density are evaluated at boiling temperature for each liquid.

	Water	Ethanol	isopropanol
T_{sat} [°C] – 1 atm	**100**	**78.37**	**82.6**
Surface tension [mN/m]	**58.81**	**17.41**	**15.98**
Density [Kg/m^3]	**973**	**733**	**727**

Results and Discussion

Figure 2 shows the result for a water drop on polytetrafluoroethylene (PTFE). The solid surface is kept at T_w=100°C. In figure 2a the temperature field measured by IR is plotted. Figure 2b shows a frame of the HSC movie. In the image the contact angle and the contact line are evaluated. In figure 2c the value of contact angle and the contact line (CL), are plotted. If the contact angle is measured while the interface (CL) is moving, it is defined as the dynamic contact angle. The equilibrium contact angle is measured in the first stage, after drop deposition, while the moving of the interface is negligible (CL~0). In this stage the drop is affected only by the wetting characteristics of the solid surface. Afterwards the CA is influenced also by evaporation phenomena and dynamic of contact line.

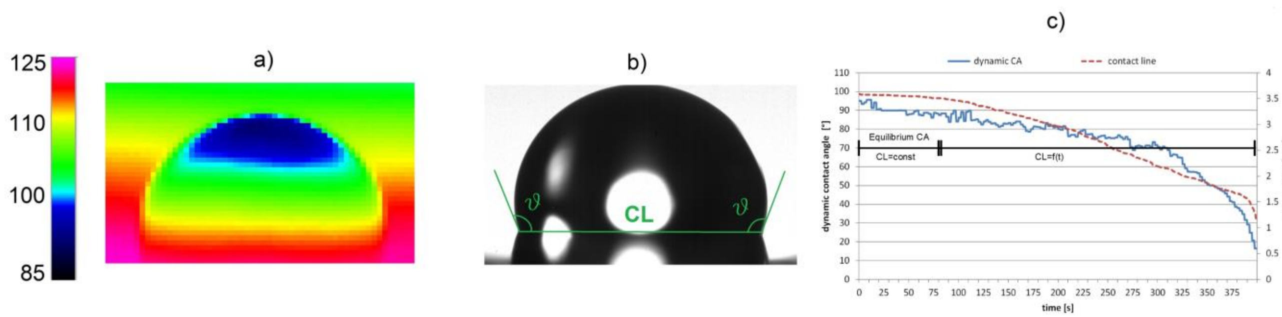

Figure 2: image analysis process. a) the IR-camera gives the temperature field on the surface of the droplet, t=1s after droplet deposition. The emission coefficient of IR-camera is fixed at 0.95 (valid for water, not for the metal surface) b) HS-camera allows to make geometrical measurements (e.g. apparent contact angles, projected contact line), t=1s after droplet deposition. c) plot of contact angle (blue line) and contact line (red dotted line) in function of time, surface is PTFE at 100 °C, liquid is water.

Nomenclature

CA	contact angle [°]
CL	contact line [mm]
HSC	high speed camera
IRC	Infrared camera

References

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