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Just How Clean Is Clean?

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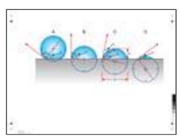

So, without question, good cleaning is essential in almost all branches of surface finishing. Though it is money well-spent, good cleaning is not without its own cost. Over-cleaning is a waste of time, money, and machinery, in some cases. This was a point made by R.N. Miller at Lockheed Aircraft[1], who used cleanliness test methods to evaluate cleaning routines prior to painting aircraft fuselages and showed that, beyond a certain point, no benefit resulted.

A great deal has been written on cleanliness testing, and $10,000 will buy a state-of-art goniometer or other sophisticated test instrumentation. At Sam Houston State University, in collaboration with our colleagues in industry, we are running an on-going program to develop more affordable cleanliness test methods. We are by no means the first with this aim. Back in the 1950s, the AESF sponsored H.B. Linford at Columbia University with this task. His research was published in *Plating* magazine at that time[2].

Half a century later, what has changed? Not a lot in terms of the physicochemical principles that underlie cleaning, but in terms of low-cost hardware and software tools, one could say that everything has changed. Today digital photography, spreadsheets and measurement software are available and portable using the miracle that is today's camera-equipped, network-connected cell phone. Our group has recently demonstrated the utility of cellphones in making contact angle measurements using the Bikerman method.[3]

Back in 1941, J.J. Bikerman[4] developed a new approach to contact-angle measurement. A droplet of known volume (v, typically 5-10 µL) is placed on a horizontal surface and viewed from above. The diameter (d) of the base of the drop is measured using a calibrated microscope or similar imaging device. The ratio d^3/v is a function of the contact angle as reported by Bikerman (Eq. 1).

$$\frac{d^3}{v} = \frac{24\sin^3\theta}{\pi(2 - 3\cos\theta + \cos^3\theta)}$$

This approach was used by Miller[1], who derived a family of nomograms for solving the equation. At SHSU, a cellphone (Fig. 1) is used to capture the image of the sessile drop (Fig. 2) and a calibration object of known dimensions.A free software program[5] is used to measure the droplet diameter. The measured values of *d* and *v* are entered along with the pixel calibration information into a spreadsheet (Fig. 3) that has been programmed to look up the corresponding contact angle.

The top-down view is only able to see the base diameter if the contact angle is 90 degrees or less, thus a “valid/invalid” signal has been programmed into the spreadsheet. Other work presently under way at SHSU aims to extend the versatility of the cellphone imaging technique so that the Bikerman approach may be used for all contact angles.

Side-on imaging allows one to view the contact angle directly. Ubiquitous image processing software such as Photoshop, CorelDraw or Meazure enable image-analysis measurement of the contact angle. Figure 4 shows an idealized implementation of this. A circle (or part of) is fitted to the profile of the droplet, and then, by drawing a radius to the point of contact with the solid surface, the contact angle can be easily determined. Alternatively, image C in Figure 4 shows the height (*h*) and the base diameter (*d*) that allow the half-angle method to be used (Eq. 2).

$$\theta_c = 2\arctan\left(\frac{2h}{d}\right)$$

These modern image analysis techniques mimic an elegant means of measuring contact angle disclosed in a 1993 patent[6]. In this instrument, the drop image was viewed in profile on a screen. An adjustable pointer was centered on the edge of the drop and used to measure the angle from the base of the drop to the apex of the drop (cf. Fig. 4C). The contact angle was read directly from the screen which was calibrated to display twice the angle ($2q_H$).

Another unique measurement method was first reported by the great surface scientist, Irving Langmuir, back in 1937[7]. He recognized that, because a droplet of liquid has a shiny surface, one can measure the angle of reflection of an incident beam of light striking the surface of the droplet. The angle of reflection can be used to determine the contact angle. Figure 5 shows a commercial instrument based on this concept from the 1970s. At SHSU, we are expanding upon this concept, using state-of-art, low-cost technology. Although it is only useful for contact angles ranging from 10 to 80 degrees, the great strength of the Langmuir method is that it gives an instant read-out of contact angle; no calculation is necessary.

Readers will note that, apart from being low cost, some of these methods are not limited to laboratory use but can be used on the shop floor, while—thanks to the cellphone—results can be transmitted to base to be archived there, if necessary.

In the laboratory, the most accurate means of cleanliness testing is the so-called axisymmetric drop shape analysis (ADSA) method where the profile of a sessile drop is computer-fitted to a mathematical equation. Professor Neumann’s research group in Toronto is foremost in the development of ADSA routines, and ADSA software is sold with all up-market goniometers. However, there are three open-source software routines, and we have reported[8] on their performance.

Finishers often have to work to prescribed ASTM (or similar) standards. This body is presently reviewing techniques for contact angle and cleanliness measurement with a sub-committee established under the leadership of Dr. Clifford Schoff. Our results are routinely passed to the sub-committee, who will in due course decide on possible updates to existing ASTM standards (9, 10 and similar).

A significant part of our mandate at SHSU is to work with our counterparts in industry and we welcome queries arising from this article. Apart from cleanliness testing techniques, we are engaged in the study of Hansen Solubility Parameters, with the aim of optimizing cleaning solvents and tailoring them to particular types of soil. “Taking the message” to industry is vital, and we are more than happy here to acknowledge our links with BFK Solutions (*bfksolutions.com*) which does just this and whose new work covering all aspects of critical cleaning seems set to become the “Bible” in its field.[11,12]

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