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Determination and Comparison of Critical Surface Tension of Glass and PTFE Surfaces Using the Zisman Method and ImageJ-Based Contact Angle Analysis

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Abstract

Wettability is a basic surface property that controls adhesion, coating, printing, and self-cleaning applications. In this study, the wettability of two contrasting reference surfaces—glass (hydrophilic, high-energy) and polytetrafluoroethylene, PTFE (hydrophobic, low-energy)—was quantitatively characterised using the Zisman method. A series of liquids of known surface tension (γ_{LV}), including ethanol, ethylene glycol, formamide, glycerol, and deionised water, were deposited as sessile droplets on each surface, and the equilibrium contact angle (θ) was measured from droplet-profile images using the open-source image analysis software ImageJ. The cosine of the contact angle was plotted against γ_{LV} for each surface, and linear regression was used to extrapolate the critical surface tension (γ_c)—the surface tension at which $\cos\theta = 1$. The extrapolated γ_c for PTFE was approximately 18.9 mN/m, consistent with literature values for PTFE. For glass, the apparent γ_c was approximately 39.8 mN/m (with the completely wetting ethanol point excluded from the fit); this value is lower than the ranges reported in the literature for glass and is discussed in Section 3. The results indicate that the combination of ImageJ-based contact angle analysis and the classical Zisman approach provides a low-cost and accessible method for estimating the critical surface tension of low-energy surfaces such as PTFE, while the value obtained for glass should be regarded as an apparent value specific to the slides and conditions used.

Keywords: Contact angle; Zisman plot; critical surface tension; wettability; ImageJ; surface energy

1 Introduction

Wettability is a term used to describe how well a liquid spreads on a solid surface and is described by the equilibrium contact angle (θ) between the liquid droplet and the solid surface. Wettability governs a broad range of industrial and everyday processes such as adhesive bonding, painting and coating, inkjet printing, textile finishing, and the design of self-cleaning or anti-fogging

surfaces. A widely used empirical approach for characterising the wettability of a solid is the Zisman method, first proposed by Zisman [1], in which the cosine of the contact angle of a series of liquids of known surface tension is plotted against the liquid surface tension. Extrapolation of the resulting linear trend to $\cos \theta = 1$ (i.e., $\theta = 0^\circ$, complete wetting) yields the critical surface tension (γ_c) of the solid—an empirical measure that is treated as a proxy for the surface free energy of the material [2].

Materials with a high γ_c (high-energy surfaces), such as glass and metal oxides, are readily wetted by most liquids owing to polar surface functional groups capable of hydrogen bonding. Conversely, materials with a low γ_c (low-energy surfaces), such as PTFE and other fluoropolymers [3], resist wetting because of their non-polar, low-polarisability C–F backbone. Despite the maturity of the Zisman method, most demonstrations rely on specialised, costly goniometers [4]. This work demonstrates that combining the classical Zisman approach with ImageJ, a free and open-source image analysis tool [5], provides an accessible and reproducible alternative suitable for teaching laboratories and preliminary surface-energy screening.

Zisman plots are most reliable for low-energy surfaces. For high-energy solids such as glass, Ozkan and Erbil [6] found that the Zisman method could not be evaluated, because such surfaces give scattered contact angle data, and they noted that the critical surface tension of glass depends on the glass composition (literature values 43–73 mN/m). Their Zisman plots were linear for the four polymer surfaces tested (R^2 between 0.98 and 1.0), but no value was assigned to glass [6]. In the present work, the Zisman method was applied to glass slides using five test liquids and ImageJ-based analysis, and the result is reported as an apparent critical surface tension for the slides used.

The study therefore has two goals: (i) to determine the critical surface tension of two contrasting, easily sourced reference surfaces—glass and PTFE—using ImageJ-based contact angle measurement and the Zisman extrapolation method, and (ii) to quantitatively confirm and compare the hydrophilic and hydrophobic character of these two surfaces, validating the method against literature-reported values.

2 Materials and Methods

This section describes how the critical surface tension of glass and PTFE was found experimentally. It first lists the substrates and test liquids (Section 2.1) and the cleaning protocol applied before each measurement (Section 2.2). It then explains how droplet images were taken and analysed in ImageJ to get contact angles (Section 2.3), and how these angles were used to construct the Zisman plots and extrapolate γ_c (Section 2.4).

2.1 Materials

Two solid substrates were selected to represent contrasting surface energies: (a) a clean glass microscope slide, representing a high-energy, hydrophilic surface, and (b) a flat polytetrafluoroethylene (PTFE) sheet, representing a low-energy, hydrophobic surface. Test liquids of known surface tension (γ_{LV}) were selected to span a wide range: ethanol (22.1 mN/m) [7], ethylene glycol (48.0 mN/m) [7], formamide (58.0 mN/m) [7], glycerol (63.4 mN/m) [6], and deionised

70 water (72.8 mN/m) [7], all at approximately 20–25 °C.

71 2.2 Surface preparation

72 Prior to each measurement, the glass slide and PTFE sheet were rinsed with ethanol, and then
73 dried in ambient air. Surfaces were handled by the edges only to avoid contamination, and
74 droplets were deposited within five seconds of drying. Between successive liquids, the surfaces
75 were cleaned again using the same procedure.

76 2.3 Contact angle measurement

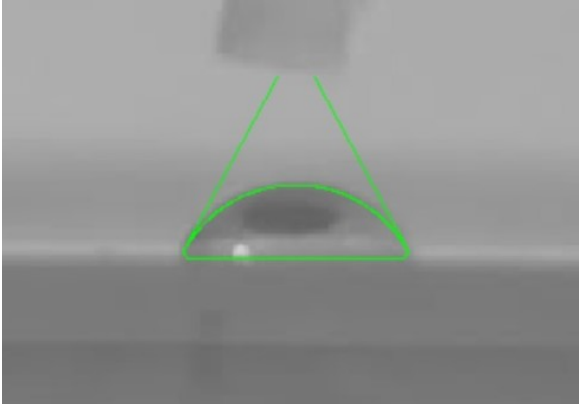


Figure 1: Deionised water droplets on glass slide

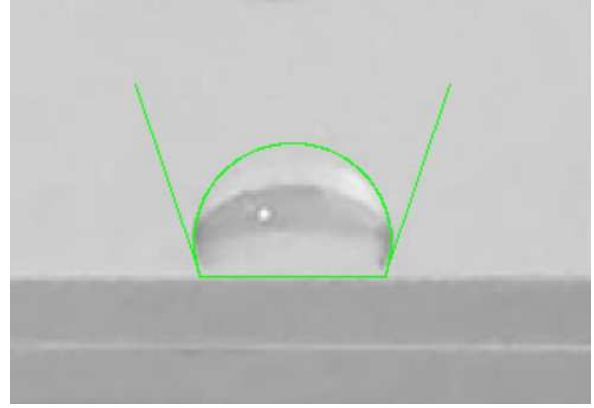


Figure 2: Deionised water droplets on PTFE sheet

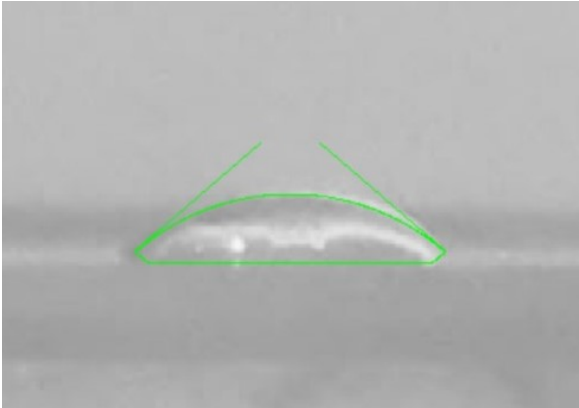


Figure 3: Glycerol droplets on glass slide

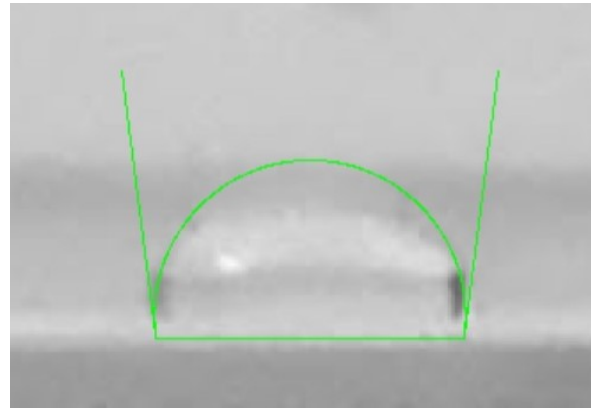


Figure 4: Glycerol droplets on PTFE sheet

77 A droplet of fixed volume (5–10 μL) of each test liquid was placed on the substrate surface
78 by means of a micropipette. Side-on images of the droplet profile were captured using a fixed
79 camera setup at a constant height and angle. Contact angles were measured from these images
80 using ImageJ [5] with the LB-ADSA (Low-Bond Axisymmetric Drop Shape Analysis) plugin [8],
81 which fits an approximation of the Young–Laplace equation to the droplet boundary in the
82 side-view image. For each liquid–surface combination, three replicate droplets were measured,
83 and the mean contact angle was calculated and used for subsequent analysis.

2.4 Zisman plot construction

For each surface, $\cos \theta$ was plotted against the corresponding γ_{LV} of each test liquid [1]. A linear regression ($\cos \theta = m \gamma_{LV} + b$) was fitted to the data for each surface, and the critical surface tension was calculated by solving for γ_{LV} at $\cos \theta = 1$: $\gamma_c = (1 - b)/m$. Points showing complete wetting ($\theta \approx 0^\circ$) carry no angular information, so the fully wetted ethanol point was left out of the glass fit.

3 Results and Discussion

This section presents the contact angles measured for the five test liquids on glass and on PTFE, followed by the Zisman plots and the critical surface tensions extracted from them. Tables 1 and 2 report the measured contact angle and the corresponding $\cos \theta$ for each liquid, and Figures 5 and 6 show $\cos \theta$ plotted against γ_{LV} together with the linear fit used for extrapolation. The resulting γ_c values are then interpreted in terms of the surface chemistry of each material and compared with values reported in the literature.

Table 1: Contact angle and $\cos \theta$ data for glass.

Liquid	γ_{LV} (mN/m)	θ ($^\circ$)	$\cos \theta$
Ethanol	22.1	0.0*	1.000
Ethylene glycol	48.0	23.6	0.916
Formamide	58.0	35.4	0.815
Glycerol	63.4	40.5	0.760
Water	72.8	48.4	0.664

*Complete wetting ($\theta \approx 0^\circ$) observed for low- γ_{LV} liquids on the high-energy glass surface. This point was excluded from the Zisman fit.

Table 2: Contact angle and $\cos \theta$ data for PTFE.

Liquid	γ_{LV} (mN/m)	θ ($^\circ$)	$\cos \theta$
Ethanol	22.1	23.7	0.916
Ethylene glycol	48.0	73.0	0.292
Formamide	58.0	87.6	0.042
Glycerol	63.4	95.4	-0.094
Water	72.8	109.2	-0.329

Linear regression of the dataset gives $\cos \theta \approx -0.01016 \gamma_{LV} + 1.404$ ($R^2 \approx 1.00$) for glass, extrapolating to $\gamma_c \approx 39.8$ mN/m, and $\cos \theta \approx -0.02454 \gamma_{LV} + 1.463$ ($R^2 \approx 0.99$) for PTFE, extrapolating to $\gamma_c \approx 18.9$ mN/m.

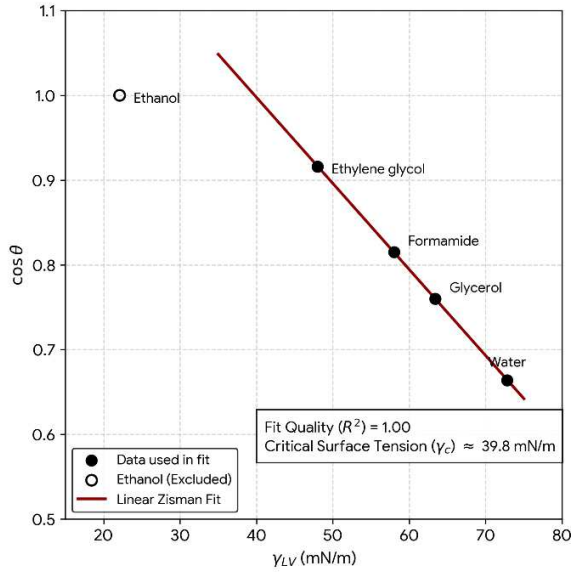


Figure 5: Zisman plot for glass

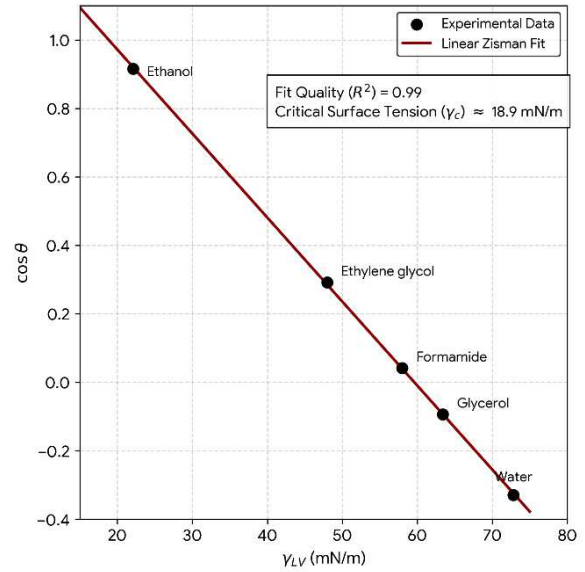


Figure 6: Zisman plot for PTFE

The markedly different slopes and intercepts of the two Zisman plots reflect the contrasting surface chemistries of glass and PTFE. The apparent γ_c obtained for glass (≈ 39.8 mN/m) is consistent with a polar, silanol-rich (Si–OH) surface that readily hydrogen-bonds with polar liquids, giving low to moderate contact angles (0 – 48°) across the tested liquid series. However, it is lower than the range of 43 – 73 mN/m reported in the literature for glass [6], and should be regarded as an apparent value for the slides used. In contrast, the low γ_c obtained for PTFE (≈ 18.9 mN/m) reflects its non-polar C–F backbone, which minimises intermolecular attraction to the test liquids; since the surface tension of water (72.8 mN/m) is far above the γ_c of PTFE, water does not wet the surface and instead forms a high contact angle ($\theta > 90^\circ$), consistent with the classical hydrophobic behaviour reported for PTFE in the literature ($\gamma_c \approx 18$ – 20 mN/m) [3].

Our glass result should be compared with that of Ozkan and Erbil [6], who could not obtain a usable Zisman line for glass. Their glass contact angles (for example, 22° for water and 83° for glycerol [6]) differ from ours (48.4° and 40.5°), and our apparent γ_c of approximately 39.8 mN/m falls below the literature range of 43 – 73 mN/m they quote [6]. Possible reasons include differences in glass composition, surface cleaning and the liquids used, since the glass in [6] was cleaned with hexane and ethanol and stored in a desiccator, whereas our slides were rinsed with ethanol. These possibilities were not tested here. The value reported should therefore be taken as an apparent γ_c for the slides used under our conditions, not as a property of glass in general.

These findings confirm the expected wetting rule: liquids with γ_{LV} below a surface's γ_c wet that surface completely, while liquids with γ_{LV} above γ_c form a finite contact angle [1]. The close agreement between the measured γ_c of PTFE and literature values [3] also serves to validate the ImageJ-based measurement methodology used in this study.

4 Limitations

The contact angles in Tables 1 and 2 are means of three replicate droplets per liquid–surface combination. The replicate-to-replicate variability (standard deviation) was not tabulated, so no error bars are shown in Figures 5 and 6 and no uncertainty could be propagated to the extrapolated γ_c values. The γ_c values are quoted to 0.1 mN/m as returned by the regression and should be read as approximate; the large difference between glass and PTFE is unlikely to be affected by this, but small differences from literature values should not be over-interpreted. Other sources of uncertainty were not quantified, including droplet-volume variation, camera alignment, baseline placement in ImageJ, and the extrapolation itself, which rests on only five test liquids. Future work should report the mean $\pm$ SD for every liquid and carry the replicate and regression uncertainty through to γ_c .

5 Conclusion

This study demonstrates that the classical Zisman method, combined with low-cost, open-source ImageJ-based contact angle analysis, provides a reliable and accessible approach to quantitatively characterise and compare the wettability of solid surfaces. Glass and PTFE were confirmed as representative high-energy (hydrophilic) and low-energy (hydrophobic) reference surfaces respectively, with critical surface tensions of approximately 39.8 mN/m and 18.9 mN/m. The method requires no specialised goniometer equipment, making it well suited to teaching laboratories, preliminary materials screening, and resource-limited research settings. Future work could extend this approach to additional surfaces (e.g., surface-treated or coated materials), a wider liquid series, and cross-validation against complementary surface energy methods such as the Owens–Wendt [9] or Fowkes [10] approaches.

Declarations

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Conflict of interest. The authors declare that they have no conflict of interest.

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