A Practical Method for Assessing Hydrophobicity of Smartphone Screen Protectors

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Abstract
Hydrophobicity is the property of a surface that repels water. In this study, the sliding behavior of water droplets on different smartphone screen protectors was analyzed as a model for static hydrophobicity. The critical tilt angle at which droplets began to slide was measured for various screen protectors. Contact angles were also recorded and used as the primary measure of surface hydrophobicity. A lower tilt angle was associated with greater hydrophobicity and vice versa. The relationship between contact angle and sliding angle was found to be well-approximated by a negative linear model within the tested range.

Keywords**:** hydrophobicity, tilt angle, screen protectors, contact angle

I. INTRODUCTION

Modern smartphones are often exposed to environments where contact with water is inevitable, whether it's rain, spills, or sweat. As a result, consumers increasingly seek screen protectors that offer water-repellent, or hydrophobic properties.[1] Many commercial screen protectors claim varying levels of water repellency, but their labelling is often unclear about the relative hydrophobicity of different models, and marketing claims such as "very water repellent" are not always reliable. It would be helpful if customers had a way to quickly and easily test the level of water repellency of phone screens, both when companies do not make explicit claims and when they make claims that may be exaggerated.

Hydrophobicity is a well-known phenomenon on "the tendency of non-polar molecules to form aggregates in order to reduce their surface of contact with polar molecules such as water".[2] In short, it is the tendency of a surface to repel water. Hydrophobic surfaces are characterized by their high contact angles with water droplets, typically above 90°, whereas hydrophilic surfaces exhibit lower contact angles, as seen in Figure 1. The standard method for measuring the level of hydrophobicity requires measuring the contact angle of a tiny water droplet, typically between 2–5 microliters (0.002–0.005 g), using lab equipment under controlled conditions.[3] This makes it practically impossible for consumers to measure, due to the specialized equipment needed to create water droplets of the required size.

In addition, contact angle, decreases with increasing droplet size due to the effects of gravity, which can make even superhydrophobic surfaces appear less hydrophobic. This makes it practically impossible for most customers to assess and compare the levels of hydrophobicity that commercial screen protectors claim. Therefore, an accessible testing method that enables customers to compare screen protectors before purchase is needed.

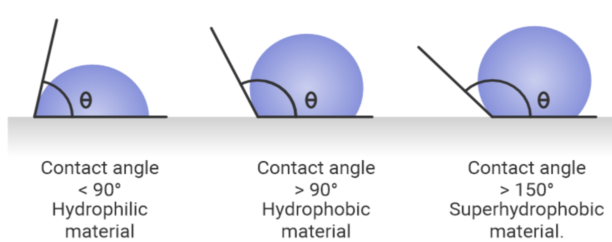

Figure 1. Levels of hydrophobicity by contact angle.[4]

The tilt angle, or sliding angle, is the angle at which a droplet of liquid begins to slide off a tilted surface.[5] This measurement can also be used to evaluate a surface's hydrophobicity.[6] As the contact angle increases, tilt angle decreases, allowing droplets to roll off the surface more easily. However, Bhushan et al only showed this for superhydrophobic surfaces, not hydrophobic surfaces such as commercial screen protectors

This study aims to build on this known relationship by extending beyond superhydrophobic surfaces to include hydrophobic surfaces such as commercial screen protectors. Specifically, we aim to demonstrate three objectives: first, to show that the relative order of contact angle among different screen protectors remains consistent regardless of drop size; second, to show that tilt angle is correlated with contact angle for non-superhydrophobic surfaces and across all drop sizes; and third, to determine which accessible droplet size is most reliable for comparing levels of hydrophobicity across all screen protectors. Together, these findings will demonstrate a practical method for customers to compare levels of hydrophobicity across different screen protectors.

II. METHODS

Five different screen protectors from various brands and made of various materials were bought for this investigation. For each screen protector, both the contact angle and tilt angle were measured using water droplets of six different masses.

Water Droplet Mass Measurement

To determine the average mass of the water droplets used, a varying number of water droplets (1-6 drops) were placed using a 1.0 mL syringe onto an analytical balance (±0.001 g). Each number of drops was measured over five trials, and the average mass was recorded.

Contact Angle Measurement

Each screen protector was cleaned with acetone and dried before testing. Using a 1.0mL syringe, water droplets (1-6 drops) were gently placed on the surface of each screen protector. A camera was placed on a tripod and positioned at a height leveled horizontally with the base of the droplet so that the side view of the water droplet was captured. Each photo was then analyzed using the "Angle Meter 360" app, where a digital protractor was used to measure the contact angle between the water droplet and the surface manually. Three trials were conducted for each number of drops on each screen protector.

Tilt Angle Measurement

To measure the tilt angle, the screen protector was placed on a tilting apparatus as shown in Figure 2. A droplet was placed onto the surface of one of the screen protectors using a syringe, and the digital protractor was reset to 0°. A video was recorded as the tilting apparatus was carefully raised, as shown in Figure 3,

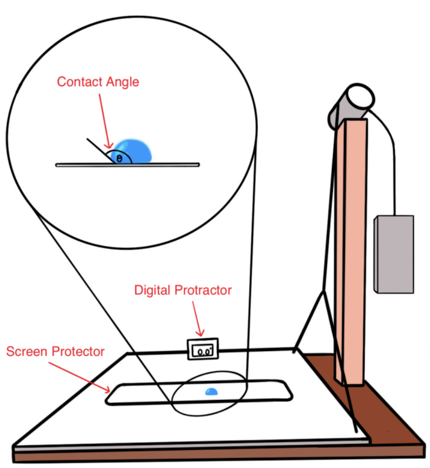

Figure 2. Set up of the tilting apparatus.

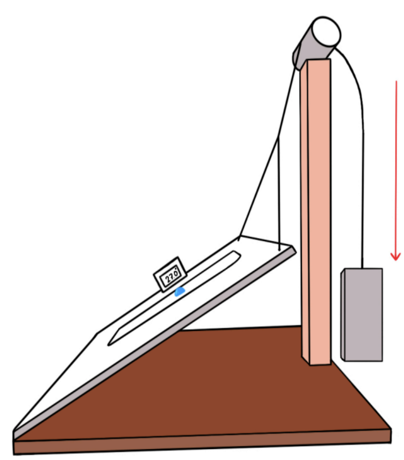

Figure 3. Tilting apparatus was slowly raised until the water droplets begin to slide.

until the water droplet began to slide. The tilting angle was then determined from the video. Six trials were conducted for each screen protector and droplet mass combination.

III. RESULTS & DISCUSSION

The average mass and calculated volume of water droplets used in the experiment are shown in Table 1. The diameters, ranging from 4.1 to 7.8 mm, are significantly larger than the standard 2-5 µL (1.6 to 2.1 mm diameter) droplets used in laboratory hydrophobicity testing.

No. of drops	Ave mass (mg)	SD (mg)	Volume (µL)	Approx. Diam. (mm)
1	35.3	1.4	35.2	4.1
2	73.3	2.7	73.1	5.2
3	115.6	4.9	115.3	6.0
4	157.3	3.7	156.8	6.7
5	210.8	6.9	210.2	7.4
6	253.8	9.1	253.0	7.8

Table 1. The average mass with the corresponding volume and diameter of the six droplet sizes tested.

As shown in Figure 4, a clear negative trend is evident across all five films, indicating that as droplet volume increases, the contact angle decreases. The consistent negative slope shown for each screen protector

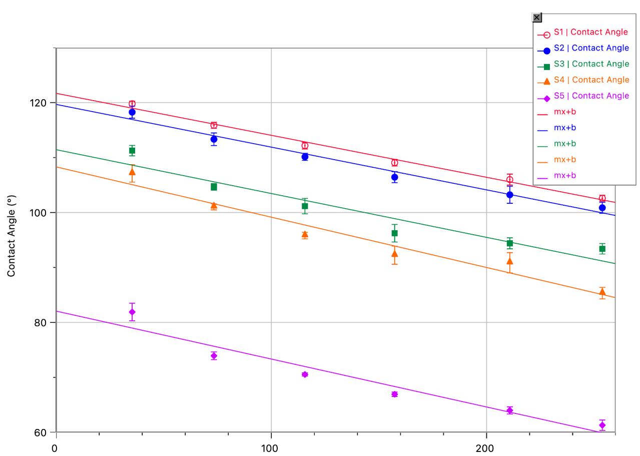

Figure 4. Relationship between volume of water droplets and contact angle for five different screen protectors.

indicates that droplet volume affects contact angle linearly. Therefore, as long as the same droplet volume is used when comparing different surfaces, the contact angle remains a valid indicator of relative hydrophobicity. Importantly, the order of relative hydrophobicity of the five screen protectors, ranked from highest to lowest as S1, S2, S3, S4, and S5, is clearly distinguishable at different droplet volumes. Even as the contact angle decreases with increasing volume, the order remains consistent across all trials. Notably, this can even be seen between two surfaces that are very close in hydrophobicity, such as S1 and S2, whose contact angles differ by only a few degrees.

Our results support Bhushan et al's findings that a higher contact angle is correlated to a lower tilt angle for superhydrophobic surfaces. However, we build on this finding by directly showing that the same holds true for commercial screen protectors, which do not exhibit superhydrophobic characteristics.

Unlike the clear negative linear trend shown in Figure 4, the change in tilt angle in Figure 5 does not show a consistent linear relationship, with the tilt angle decreasing at a decreasing rate with increasing drop volume. However, while the tilt angle is not linearly related to the volume of droplets, this does not have any impact on the objective of this research, which is to assess whether tilt angle can serve as a reliable method of comparing the hydrophobicity of large drop sizes.

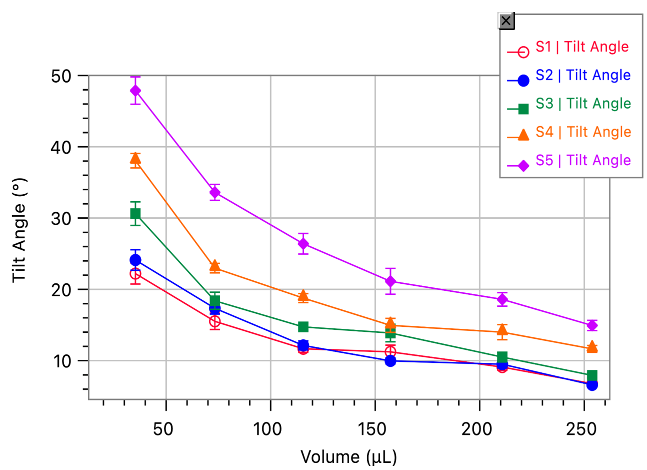

Figure 5. Relationship between tilt angle and the volume of water droplets for five different screen protectors.

The tilt angle result shown in Figure 5 shows the same relative ranking of the screen protectors as observed in Figure 4. In contrast to the contact angle, which increases with higher hydrophobicity, the tilt angle is inversely related to hydrophobicity, meaning that the most hydrophobic screen protector (S1) requires the lowest tilt angle for droplets to slide, while the least hydrophobic screen protector (S5) requires the highest tilt angle. Again, for the smallest droplet volume, even surfaces that are very close in hydrophobicity, such as S1 and S2, still remain distinguishable. However, as droplet volume increases, the difference between these two becomes less significant. This suggests that while the tilt angle is a practical and accessible method for comparing the hydrophobicity of surfaces, it becomes less reliable and harder to distinguish between surfaces with very close hydrophobicity as droplet volume increases. Therefore, for consumer testing, such as identifying the most water-repellent screen protector, it is recommended to use a single small water droplet to ensure the most accurate results.

We have shown that first, the relative order of contact angle among different screen protectors remains the same across a wide range of droplet sizes, even though contact angle decreases with increasing drop volume due to gravity. Second, tilt angle is consistently inversely correlated with contact angle. And finally, by comparing different drop sizes, the most reliable drop size for assessing the hydrophobicity of screen protectors is identified. Altogether, our findings show that using the tilt angle of a single typical drop is a reliable method that consumers can use to quickly and reliably measure the relative hydrophobicity levels of smartphone screen protectors.

Further research is recommended investigate how human contact, such as exposure to sweat, skin oil, and repeated touch, affects the contact and tilt angles over time. This would help evaluate whether the hydrophobicity properties of a screen protector will degrade with real-world use.

IV. CONCLUSION

It has been shown that tilt angle of a drop of typical size can be used to reliably compare the hydrophobicity of surfaces such as commercial screen protectors. However, its reliability decreases with higher drop volume. Therefore, using a single small water droplet in tilt angle testing provides the most accurate and accessible method for consumers to assess the hydrophobicity of commercial screen protectors.

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