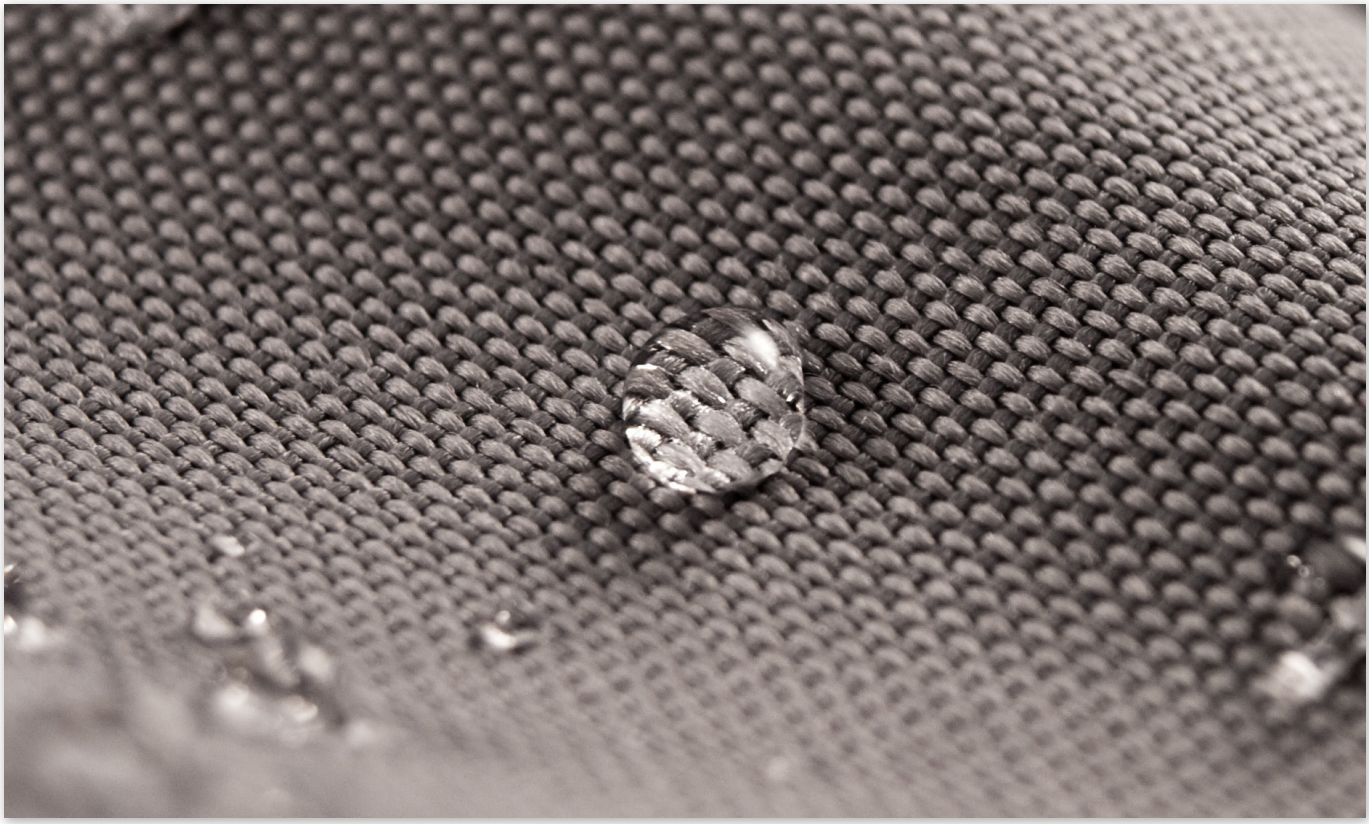
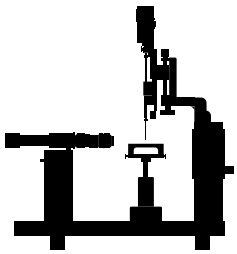


Application Note

Recommended test liquids selection for surface energy determination according to OWRK

Surface free energy (SFE) is one of the most critical surface parameters in industrial manufacturing processes such as painting, coating, printing, and adhesive bonding. The success of these processes strongly depends on proper wetting of the substrate surface — and wetting behavior is directly governed by the surface free energy of the solid. A widely used method for determining solid SFE is the Owens–Wendt–Rabel–Kaelble (OWRK) method, which divides the total surface energy into two components: Dispersive (non-polar) and Polar. To calculate these components, contact angles of at least two test liquids must be measured on the substrate surface. However, the selection of suitable test liquids is not arbitrary — it has a direct and significant impact on the reliability, stability, and accuracy of the calculated surface energy values. For robust OWRK analysis, DataPhysics Instruments[1] recommends the use of diiodomethane, thiodiglycol, and ethylene glycol. The following application note explains the selection criteria and demonstrates how to choose the test liquids.

Measurement device
Optical contact angle measuring and contour analysis systems – OCA series



Measurement method
Optical contact angle measuring and contour analysis systems

Measured quantities
Contact angle
Surface energy

Environmental conditions
Room temperature

Samples
Solid surface

Industries
Coatings
Pre-treatment or cleaning process on a solid surface
Printing

dataphysics

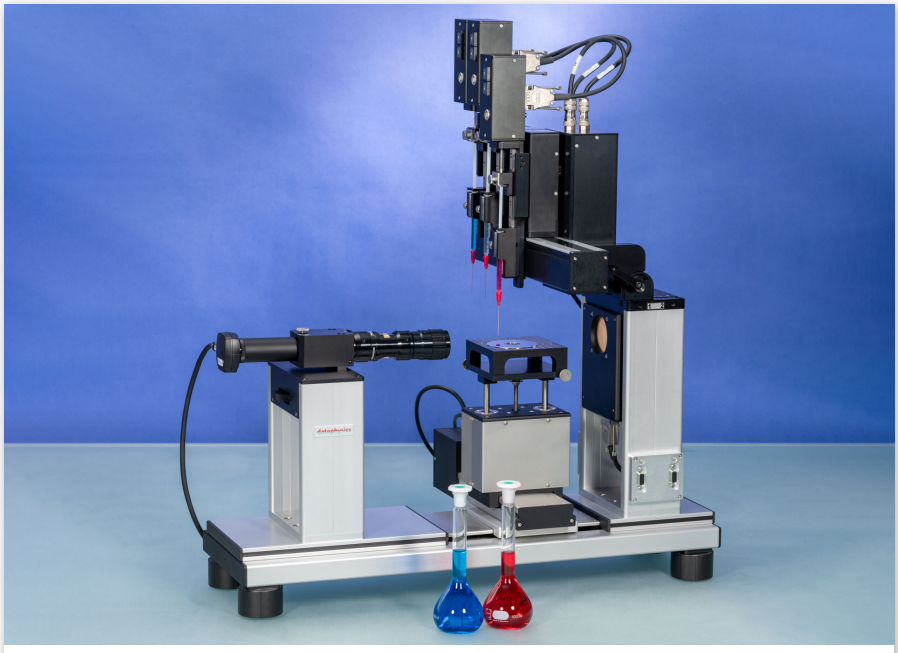


Fig. 1: The optical contact angle measuring and contour analysis systems of the OCA series manufactured by DataPhysics Instruments

Theory

Based on an appropriate model, the surface energy (SFE) of a solid, including its dispersive and polar parts, can be determined by contact angle (CA) measurements with at least two different test liquids, whose surface tensions including their dispersive and polar parts are known. The Owens, Wendt, Rabel and Kaelble (OWRK-model) is the most commonly used method[2][3][4], which considers the geometric mean of the dispersive σ^d and polar parts σ^p of the liquid's surface tension σ_l and of the solid's SFE σ_s, the interfacial tension σ_{sl} between the solid and a liquid (equation 1):

$$\sigma_{sl} = \sigma_s + \sigma_l - \left\{2 \cdot \left(\sqrt{\sigma_s^d \cdot \sigma_l^d} + \sqrt{\sigma_s^p \cdot \sigma_l^p}\right)\right\} \quad (1)$$

$$\sigma_s = \gamma_{sl} + \sigma_l \cdot \cos\theta \quad (2)$$

By substituting this expression in the ***Young equation*** (2) a linear equation of the type y = mx + b can be obtained:

$$\underbrace{\frac{\sigma_l \cdot (1+\cos\theta)}{2\sqrt{\sigma_l^d}}}_{y} = \underbrace{\sqrt{\sigma_s^p}}_{m} \cdot \underbrace{\sqrt{\frac{\sigma_l^p}{\sigma_l^d}}}_{x} + \underbrace{\sqrt{\sigma_s^d}}_{b} \quad (3)$$

In equation 3, y and x contain known quantities, namely the measured CA and the dispersive and polar parts of the test liquid's surface tension. The searched dispersive and polar parts of the solid's SFE are contained in the axis intercept b and in the slope m, respectively. These parameters can be evaluated creating a regression line (Fig. 2) when CAs of at least two test liquids are measured.

Requirements for Test Liquids

The selection of suitable test liquids is essential for reliable surface energy determination. Test liquids must fulfill both practical handling requirements and defined physicochemical criteria to ensure accurate OWRK evaluation.

- ***Handling and safety***

For optical contact angle measurements (OCA) (see Fig. 1), only very small liquid volumes are required, typically in the microlitre range.

Test liquids should:

√ Be safe and easy to handle (check SDS and GHS classification)

√ Exhibit good chemical stability (no rapid degradation due to light, oxygen, or moisture)

√ Not react with or alter the substrate surface

√ Have low vapour pressure to prevent evaporation during measurement

Stable and non-reactive liquids help ensure reproducible and reliable contact angle data.

- ***Physicochemical criteria***

For surface energy determination according to OWRK, the following properties are required:

√ Known total surface tension

√ Known dispersive and polar parts of the surface tension

√ High purity and stable composition

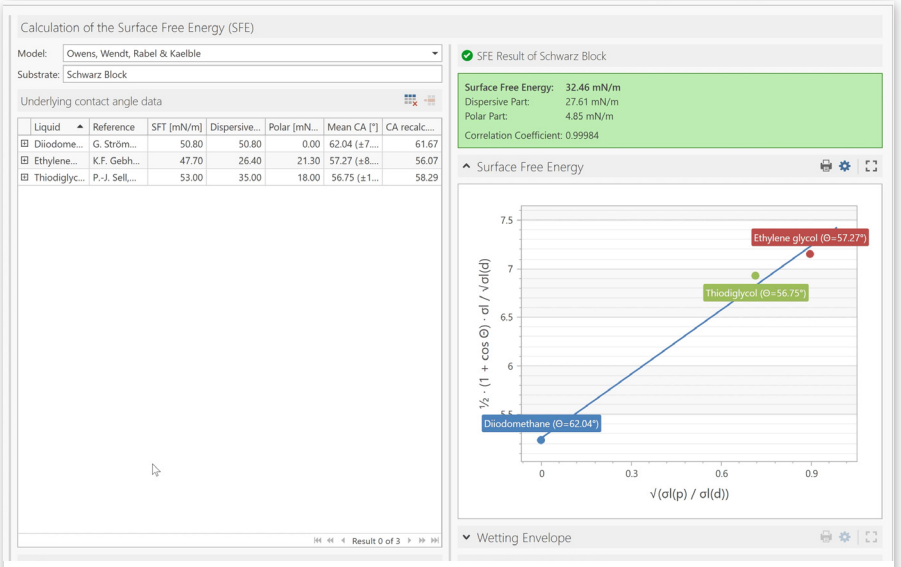


Fig. 2: Evaluation of the surface energy with the software from DataPhysics Instruments according to the OWRK model

Although literature values are often available, verification of surface tension by pendant drop or tensiometric measurement is recommended to exclude contamination. In addition, liquids with relatively high surface tension are preferred. They form measurable contact angles rather than spreading completely, improving regression stability and evaluation accuracy.

- ***Number of test liquids***

As described in the **Theory** section, the surface energy of a solid according to the OWRK method can be calculated from the measured contact angles and the known surface tension components of at least two liquids.

Although two test liquids are mathematically sufficient to define a regression line, a two-point evaluation does not provide information about the reliability of the measurement. Any unnoticed error in one contact angle measurement may directly lead to an incorrect surface energy result. Further details can be found in the application note: ***"Why measuring with at least three test liquids is recommended for Surface Energy analysis"***

For this reason, DataPhysics Instrument recommends using **three different test liquids**. Additional data points improve the stability of the regression, enable the identification of potential outliers, and increase the overall accuracy of the evaluation. Furthermore, the selected liquids should have significantly different polar-to-dispersive ratios to ensure well-separated data points and a robust surface energy determination.

Recommended Test Liquids Set

The following table presents a possible selection of suitable test liquids evaluated according to the criteria outlined above. Based on these considerations, **DataPhysics Instrument recommends diiodomethane, thiodiglycol, and ethylene glycol as the preferred test liquids** for contact angle measurements and subsequent surface energy determination according to the OWRK method. These substances present manageable handling risks, particularly since only very small volumes are required for optical contact angle measurements (e.g., with the OCA systems). Ethylene glycol is chemically stable, while thiodiglycol and diiodomethane, although slightly sensitive to light, remain sufficiently stable for reliable measurements when stored properly. Storage in light-protected containers is recommended. In addition, their relatively low vapour pressures prevent rapid evaporation during measurement.

All three recommended liquids exhibit surface tensions above 47 mN/m, minimizing unwanted spreading and enabling stable, measurable contact angles on most solid surfaces. Most importantly, they provide excellent contrast in their dispersive and polar surface tension components:

- *Diiodomethane: purely dispersive with 0% of polar part*
- *Thiodiglycol: significant polar contribution with 27% of polar part*
- *Ethylene glycol: higher polar contribution with 35% of polar part*

This wide distribution ensures well-spaced data points in the OWRK plot, resulting in a robust regression line and reliable determination of the solid's surface energy.

Table 1: Possible and recommended test liquids

Chemical Identification	Name	Diiodomethane	Benzyl Alcohol	Thiodiglycol	Ethylene Glycol	Glycerine	Water
	Molecular Formula	CH_2I_2	C_7H_7OH	$S(C_2H_4OH)_2$	$C_2H_4(OH)_2$	$C_3H_5(OH)_3$	H_2O
Recommendation	Preference Level	★★★	★★☆	★★★	★★★	★☆☆	★★☆
Surface Tension Data (25 °C) [2][3][4]	Total Surface Tension σ (mN/m)	50.8	38.9	54.0	47.7	63.4	72.8
	Dispersive Part σ^d (mN/m)	50.8 (100%)	29.0 (74.6%)	39.2 (72.6%)	30.9 (64.8%)	37.0 (58.4%)	21.8 (29.9%)
	Polar Part σ^p (mN/m)	0 (0%)	9.9 (25.4%)	14.8 (27.4%)	16.8 (35.2%)	26.4 (41.6%)	51.0 (70.1%)
	$\sqrt{(\sigma^p/\sigma^d)}$ (WORK x-value)	0.0000	0.5843	0.6145	0.7374	0.8447	1.5295
Safety [5]	GHS Classification	Dangerous if swallowed/inhaled; skin & eye irritation	Harmful if inhaled/swallowed; severe eye irritation	Causes serious eye irritation	Harmful if swallowed; organ damage (kidneys) after prolonged exposure	–	–
Stability [5]	Chemical Stability	Light sensitive	Oxidizes slowly	Slightly light sensitive	Stable	Stable	Stable
	Vapour Pressure	1.60 mbar (25 °C)	0.027 mbar (20 °C)	0.0011 mbar (20 °C)	0.12 mbar (25 °C)	0.00121 mbar (40 °C)	31.71 mbar (25 °C)
Handling [5]	Description/ Characteristics	Colourless; light sensitive. Discard if significantly discoloured.	Colourless; slight aromatic odour.	Viscous; slightly light sensitive. Discard if significantly discoloured.	Colourless, viscous	Viscous, hygroscopic; store dry and tightly closed.	Highly polar; may cause spreading ("runaways"). Use distilled water and store in glass containers.

Caution when using water:

Water is a commonly used and readily available test liquid. It is non-toxic, chemically stable, and has a high surface tension (72.8 mN/m) with approximately 70% polar contribution, which in principle makes it suitable for surface energy analysis. In particular, **water is very useful for quality control and routine wettability checks**.

However, due to its strong polarity, such as its high polar component, hydrogen bonding capability, and sensitivity to contamination and surface heterogeneity, water can sometimes produce outlier measurements. Therefore, it should not be used as one of only two test liquids in scientific surface energy analysis. If used, it is recommended as:

- *A third liquid (allowing exclusion in case of outliers), or preferably*
- *A fourth liquid in combination with diiodomethane, thiodiglycol, and ethylene glycol.*

This approach ensures reliable regression while maintaining control over potential measurement deviations.

Summary

For reliable OWRK surface energy analysis, DataPhysics Instruments recommends using diiodomethane, thiodiglycol, and ethylene glycol. This combination provides a broad range of polar and dispersive parts, ensuring stable regression and accurate results.

Water is very useful for quality control and routine wettability checks. It may be included as an additional test liquid; however, it should not be used as one of only two liquids for scientific surface energy evaluation.

Reference

[1] www.dataphysics-instruments.com/
[2] Kaelble, H., J. Dispersion-Polar Surface Tension Properties of Organic Solids. *Adhesion*, **1970,** *2*, 66-81.
[3] Owens, D., Wendt, R. Estimation of the Surface Free Energy of Polymers. *J. Appl. Polym. Sci.*, **1969**, *13*, 1741-1747.
[4] Rabel, W. Einige Aspekte der Benetzungstheorie und ihre Anwendung auf die Untersuchung und Veränderung der Oberflächeneigenschaften von Polymeren. *Farbe und Lack*, **1971**, *77*, 10.
[5] https://chemicalsafety.com

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