Application Report

Application report: AR300

Industry section: Inkjet printing

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Methods:

Bubble Pressure Tensiometer – BP100
Drop Shape Analyzers – DSA30E & DSA100E

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Surface Tension and Wettability Analysis of Ink Formulations Using Static and Dynamic Methods

Combining surface analysis methods for targeted ink optimization

Surface tension and wettability play a fundamental role in the performance of liquid formulations in various industrial applications, including coatings, printing, and adhesion processes. The ability of a liquid to spread, adhere, or be absorbed by a substrate is governed by its surface tension properties and the interaction between the liquid and the solid surface.

Inks, coatings, and other liquid formulations often contain surfactants, which regulate surface tension and influence spreading behavior. Static surface tension provides an equilibrium measure of a liquid's cohesive forces, while dynamic surface tension describes how quickly surfactants migrate to the interface under rapid application conditions. Additionally, the wettability of a substrate, as determined by contact angle measurements, dictates the adhesion and absorption characteristics of the liquid.

This study aims to analyze the static and dynamic surface tension of ink formulations and their wettability on different substrates. By utilizing advanced surface science techniques, we seek to understand how these properties affect formulation performance and optimize application processes.

Background

The performance of liquid formulations in industrial applications is highly dependent on their surface tension characteristics. Whether in coatings, printing, or adhesion processes, the ability of a liquid to wet and spread on a substrate determines its effectiveness. Surface tension influences these behaviors by controlling the balance between cohesive and adhesive forces at the interface.

Surface tension can be classified into two key categories: static and dynamic. Static surface tension represents the equilibrium state of a liquid and provides insight into its stability and long-term wetting properties. Dynamic surface tension, on the other hand, is time-dependent and plays a critical role in fast-paced industrial processes where the liquid is applied rapidly, such as during high-speed coating or printing. The interplay between these two parameters dictates how well a formulation can perform in real-world applications.

Inks, in particular, require a precise balance of surface tension to ensure optimal performance. If the surface tension is too high, the ink may not spread effectively, leading to poor substrate coverage. Conversely, if the surface tension is too low, the ink may spread excessively, causing defects such as misting or bleeding. Understanding both static and dynamic surface tension is therefore essential for developing formulations that achieve consistent and reliable performance.

Dynamic surface tension is particularly crucial in inkjet printing, where the formation of stable ink droplets is essential for achieving high-quality prints. The ability of an ink to "jet" effectively depends on the interplay of viscosity and dynamic surface tension. If the surface tension does not adjust quickly enough, satellite droplets may form, leading to poor print resolution and inconsistent drop sizes. A well-balanced formulation ensures stable drop formation and minimizes defects, improving printing performance.

Additionally, the interaction between an ink and a substrate is not solely governed by surface tension but also by the surface properties of the solid material. Wettability, as determined by contact angle measurements, provides a deeper understanding of how a liquid interacts with different substrates, whether hydrophobic or porous. This study integrates surface tension analysis with wettability characterization to offer a comprehensive evaluation of ink behavior across various surfaces.

This report investigates the static and dynamic surface tension of three ink formulations – *Original Ink*, *Customer Formulation Ink*, and *Similar Ink* – using the pendant drop method for static measurements and the maximum bubble pressure method (BP100) for dynamic evaluations. By analyzing surface tension kinetics and substrate interactions, this study provides valuable insights into optimizing ink formulations for enhanced spreading, adhesion, and absorption behavior in real-world applications.

Experimental section

Materials and sample preparation

Three different ink formulations – *Original Ink*, *Customer Formulation Ink*, and *Similar Ink* – were analyzed to evaluate their wetting and spreading properties. The inks were tested on both a hydrophobic Polydimethylsiloxane (PDMS) substrate and an absorbent paper substrate to simulate industrial application conditions.

Static surface tension measurement

Static surface tension was determined using the pendant drop method on the DSA30 Drop Shape Analyzer. A glass syringe was filled with each ink sample, and pendant drops were formed at the needle tip. The surface tension was calculated by analyzing the drop shape using the Young-Laplace equation. Measurements were performed at room temperature (25 °C), with ten replicates to ensure accuracy. This method provides insights into the equilibrium state of ink, which is crucial for formulation stability.

Dynamic surface tension measurement

Dynamic surface tension was measured using the BP100 Bubble Pressure Tensiometer, which operates on the maximum bubble pressure method. In this method, a gas bubble forms at the tip of an immersed capillary, with its curvature increasing until reaching maximum pressure when the bubble's radius equals the capillary radius.

Figure 1: Measurement of dynamic surface tension of an ink with a BP100 Bubble Pressure Tensiometer.

By varying the frequency of bubble formation, surface tension is measured at different surface ages (from 10 ms to 10,000 ms), representing ink behavior under high-speed application conditions. This technique provides data on how quickly surfactants migrate to the interface, affecting drop formation and spreading behavior.

Contact angle and substrate interaction analysis

Contact angle measurements were performed on PDMS and paper substrates using the DSA100 Drop Shape Analyzer. Sessile drop measurements were recorded with a high-speed camera to capture time-dependent wetting behavior. The surface free energy of the substrates was determined by analyzing the polar and disperse components of the ink-substrate interaction. This data helps assess adhesion strength and spreading dynamics.

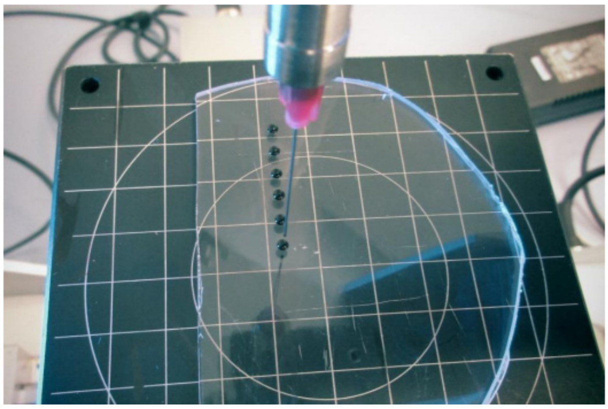

Figure 2: Contact angle measurement of ink droplets

Results and discussion

Static surface tension and ink formulation stability

The static surface tension values, obtained via pendant drop analysis, were as follows:

- Original Ink: 29.95 mN/m
- Customer Formulation Ink: 26.77 mN/m
- Similar Ink: 29.75 mN/m

These values indicate that *Customer Formulation Ink* has the lowest equilibrium surface tension, suggesting that it contains more effective surfactants for reducing interfacial energy. This characteristic enhances wetting and spreading, particularly on non-porous substrates. The similar values between *Original Ink* and *Similar Ink* suggest comparable formulation characteristics.

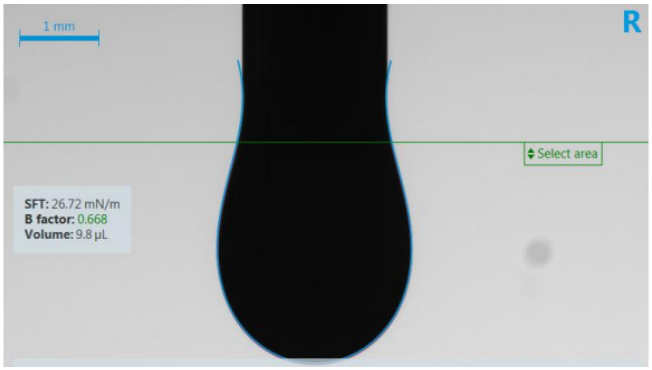

Figure 3: An exemplary image of pendant drop measurement of *Customer Formulation Ink*.

Dynamic surface tension and its relevance to application processes

Dynamic surface tension measurements revealed differences in ink behavior under rapid surface age conditions. The BP100 results (Fig. 4) showed that *Customer Formulation Ink* showed the fastest reduction in surface tension, stabilizing at equilibrium within shorter timeframes and also exhibited the lowest initial and final surface tension. This suggests that the surfactants in this formulation are highly efficient in migrating to the air-ink interface.

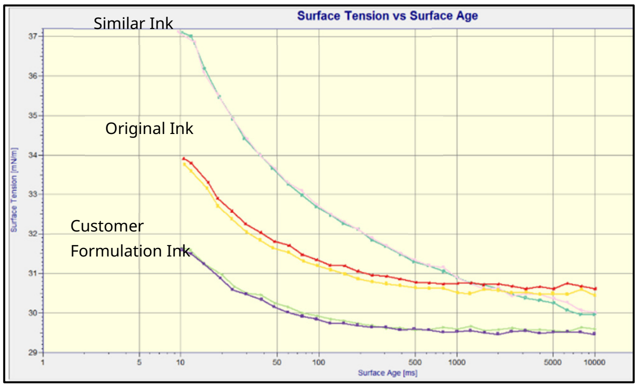

Figure 4: Dynamic surface tension curves from BP100 measurements.

In contrast, the *Similar Ink* displayed a more pronounced time dependence, indicating a slower surfactant response. This behavior can lead to inconsistencies in drop formation and wetting in high-speed applications. The *Original Ink* exhibited intermediate behavior, suggesting a balance between stability and responsiveness. Its surface tension decreased at a moderate rate, suggesting a formulation that provides controlled spreading without excessive fluctuations.

These findings highlight the importance of dynamic surface tension in ensuring controlled wetting and adhesion in industrial applications, particularly for processes requiring precise ink deposition.

Wetting behavior on hydrophobic and absorbent substrates

Contact angle measurements on PDMS demonstrated that *Customer Formulation Ink* achieved the lowest initial contact angle, confirming its superior wetting ability on hydrophobic surfaces. *Original* and *Similar Ink* exhibited slightly higher contact angles, which could lead to less uniform spreading in non-porous applications.

The time-dependent behavior of contact angles on PDMS revealed that all inks showed a gradual reduction in contact angle over time, indicating dynamic spreading on this hydrophobic substrate. This suggests that the surfactants within the inks are actively migrating to the interface, although at different rates. Notably, the static contact angles were measured 10 seconds after droplet deposition to ensure a consistent evaluation.

An analysis of polar and disperse components further supports these observations. The *Customer Formulation Ink* exhibited the lowest disperse component (17.1 mN/m) and polar component (9.7 mN/m), which likely contributed to its enhanced wetting performance on PDMS. In contrast, the *Similar Ink* showed a slightly higher polar component (11.5 mN/m), which may have influenced its reduced spreading efficiency. The *Original Ink* displayed an intermediate balance between disperse and polar interactions, aligning with its moderate wetting performance.

On paper, all three inks demonstrated rapid absorption, with contact angles decreasing sharply within milliseconds. This highlights the dominant role of substrate porosity in determining ink behavior. However, the *Similar Ink* displayed slightly slower absorption, which may be attributed to differences in viscosity or surface tension kinetics.

Overall, these findings emphasize that ink adhesion on paper is primarily driven by capillary action, whereas wetting on PDMS depends on the interplay between disperse and polar forces. The observed variations in surface tension dynamics and polar-disperse interactions underline the importance of tailoring ink formulations for specific applications, ensuring optimal performance across different substrates.

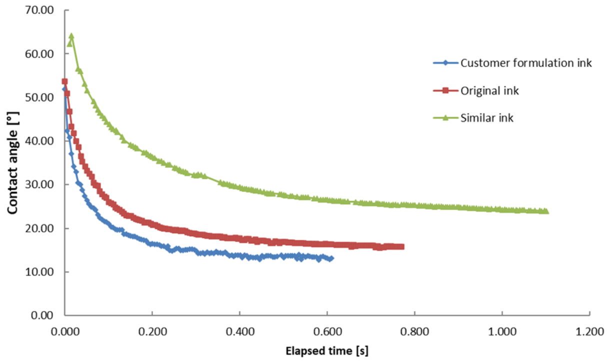

Figure 5: A comparison of exemplary contact angle measurements of three inks on paper

Conclusion

This study highlights the importance of both static and dynamic surface tension in optimizing liquid formulations. Static surface tension measurements provide insights into equilibrium wetting and formulation stability, while dynamic surface tension analysis reflects surfactant efficiency in reducing interfacial energy under rapid application conditions. Contact angle measurements, along with the determination of polar and disperse components, further clarify how ink-substrate interactions influence adhesion and spreading behavior.

Among the tested inks, *Customer Formulation Ink* exhibited the most favorable wetting properties, with low static surface tension, rapid surfactant response in dynamic conditions, and strong adhesion to both hydrophobic and absorbent substrates. The *Original Ink* demonstrated balanced characteristics, making it versatile for a range of applications. Meanwhile, the *Similar Ink* showed slower dynamic behavior, which could affect its performance in high-speed processes requiring rapid wetting. Understanding these surface properties allows manufacturers to tailor formulations for improved efficiency, uniform deposition, and enhanced adhesion across diverse substrates.

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