Application Report

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Optimizing Shampoo Foam Analysis: A Comparative Study of Measurement Techniques

Evaluating the effectiveness of Sparging, Foam Flash, and Adapted Foam Flash

Foam is a critical attribute of shampoo formulations, serving as a functional element in the cleansing process and as a key determinant of consumer satisfaction. While the main role of shampoos is to remove sebum, dirt, and styling residues, the sensory experience – particularly the quality of foam – profoundly influences user perception. Rich, stable lather is often equated with efficacy, driving demand for products with consistent foaming performance. However, analyzing foam behavior is challenging, as properties like foam height, stability, and bubble structure are influenced by surfactant chemistry, stabilizers, and application dynamics.

Foam formation and stability are critical properties in shampoo formulations, directly influencing user perception and product performance. The ability to control foaming behavior is essential for developing shampoos with desirable sensory attributes and effective cleansing properties. This study investigates the foaming behavior of four different shampoo formulations using the Dynamic Foam Analyzer – DFA100. The objective was to evaluate different foam generation methods and determine their effectiveness in characterizing foam height, structure, stability, and drainage behavior. The insights gained from this study contribute to formulation optimization and improved product performance.

Background

Shampoos are formulated to cleanse the scalp and hair by effectively removing sebum, dirt, and styling residues while delivering a sensory experience that aligns with consumer expectations. The evolution of modern shampoos began in the early 20th century, with liquid formulations introduced in 1927 and the advent of synthetic surfactants in the 1930s. These innovations laid the foundation for advanced formulations, such as silicone-conditioning shampoos in the 1980s, which integrated cleansing with hair-smoothing benefits. Today, shampoo formulations range from basic cleansing agents to multifunctional products enriched with conditioning agents, proteins, vitamins, and specialized actives. Despite their diverse compositions, all shampoos must meet core performance criteria, including efficient lathering, thorough rinsing, and leaving hair feeling soft and manageable.

Foam, a dispersion of gas bubbles within a liquid matrix, is a critical attribute influencing shampoo performance and consumer perception. Foam formation is governed by surfactants – amphiphilic molecules that adsorb at the air-water interface, reducing surface tension and facilitating the stabilization of gas-liquid interfaces. Primary surfactants, such as sodium lauryl sulfate (SLS), provide cleansing efficacy by emulsifying oils, while secondary surfactants (e.g., cocamidopropyl betaine) and foam stabilizers enhance foam texture, density, and longevity. These components work synergistically to produce a rich, stable lather, which consumers often associate with superior cleansing and product quality. Although transient in nature – since shampoo foam need only persist during application—its structure and stability significantly influence user satisfaction.

Foam stability is dictated by interfacial properties and colloidal dynamics. Due to their inherently high interfacial free energy, foams are thermodynamically unstable and decay through processes such as liquid drainage (gravity-driven flow of liquid from the foam), coalescence (merging of bubbles), and disproportionation (gas diffusion from smaller to larger bubbles). Key parameters, including drainage half-life (the time required for half of the liquid to drain from the foam) and mean bubble size (a measure of bubble coarsening and structural integrity), serve as quantitative indicators of foam stability. Uniformly sized, finer bubbles enhance foam density and perceived creaminess, while rapid liquid drainage and excessive bubble growth indicate poor foam stability. Advanced analytical techniques, such as the KRÜSS Dynamic Foam Analyzer – DFA100, enable precise characterization of foam behavior by simulating real-world agitation and capturing time-resolved data on foam height, volume, and decay kinetics. High-speed imaging and image analysis further provide detailed insights into foam morphology, generating bubble size distribution histograms that link formulation components to foam quality.

The interplay between formulation science and consumer perception underscores the significance of foam analysis in shampoo development.

Experimental section

Four shampoo samples, labeled Sample 1 to Sample 4, were analyzed using the KRÜSS Dynamic Foam Analyzer – DFA100. Three distinct methodologies – Sparging, Foam Flash, and a Adapted Foam Flash protocol – were employed to determine the optimal method for differentiating foam characteristics. Each experiment was conducted at a controlled temperature of 20 °C ±2 °C, with real-time monitoring of foam height, bubble size distribution, and liquid drainage over a 30-minute period to assess foam stability and structural integrity. The DFA100 system, in conjunction with ADVANCE software, ensured accurate data acquisition. Each sample was tested in duplicate to ensure reproducibility.

Sparging

The Sparging method involved controlled air introduction through a porous paper filter (12–25 µm pore size, FL4551) to generate foam. Shampoo samples were diluted in a 1:4 shampoo/water ratio, resulting in a total sample volume of 50 mL, and mixed within the CY4572 40 mm prism measuring column. Air was sparged at a flow rate of 0.3 L/min until a total gas volume of 100 mL had been pumped.

Foam Flash

Foam Flash is a method available in the ADVANCE software that works with a stirring module and is primarily intended for the analysis of highly foaming liquids. The method simulates repeated agitation by using cyclic stirring.

Shampoo samples were diluted in a 1:2 shampoo/water ratio, resulting in a total sample volume of 60 mL. Stirring was performed at 3000 rpm using the SR4501 stirrer in 30 cycles, each consisting of 5 seconds of stirring followed by a 5-second pause.

Adapted Foam Flash

The Adapted Foam Flash method aimed to ensure reproducible foam generation and measurement for this particular task. Shampoo samples were diluted in a 1:2 ratio and mixed directly in the measuring column (SH4512 + SR4501) with a total volume of 60 mL. The homogenization phase was conducted at 400 rpm for 15 seconds to prevent premature foam formation, followed by high-speed stirring at 3000 rpm in 5-second oscillation periods for 20 seconds to induce foam.

Results and discussion

Sparging method

The Sparging method produced uniformly high foam volumes (~100 mL) across all samples, with minimal differences in foam height or structure. The aggressive air introduction led to coarse bubble formation and similar size distributions, homogenizing properties across formulations. While this method confirmed all shampoos as "high-foamers" and generated large foam volumes, its high gas retention limited sensitivity to formulation-specific differences, as consistently high measurements were observed across all tested shampoos.

To further understand the foam characteristics, key parameters were analyzed. The foam height (h_{foam}) represents the height of the foam layer generated during the experiment and is a crucial indicator of foam stability over time. A higher h_{foam} suggests better foam persistence, which is desirable in applications where long-lasting foam is beneficial. The liquid height (h_{liquid}) corresponds to the remaining liquid phase beneath the foam. This measurement is particularly important as it reflects the drainage behavior of the foam; a rapid decrease in h_{liquid} can indicate poor foam stability due to excessive liquid drainage. The total height (h_{total}) is the sum of the foam and liquid heights, providing an overall measure of the foam structure within the test setup. Together, these height parameters help assess the efficiency of different foaming methods in distinguishing between shampoo formulations.

In addition to foam height measurements, the bubble structure was characterized using the bubble count (BC) and the mean bubble area (MBA). The BC represents the number of bubbles per unit area and serves as a measure of foam density. A higher BC indicates a finer, more stable foam with numerous small bubbles, whereas a lower BC suggests coarser foam with fewer but larger bubbles. The MBA quantifies the average size of the bubbles within the foam and provides insight into bubble coalescence and liquid drainage over time. A steady increase in MBA generally indicates foam instability, as larger bubbles form due to the merging of smaller ones, leading to faster foam collapse. By analyzing these parameters, differences in foam structure and longevity between shampoo formulations can be effectively evaluated.

Foam Flash method

Cyclic stirring with the Foam Flash method produced nearly identical foam heights and decay patterns across all samples, with maximum foam heights clustering within a narrow range and minimal variation in drainage behavior. The repeated mechanical agitation applied high shear forces, accelerating foam collapse and reducing stability by causing uniform bubble rupture and drainage. This intense agitation "smashed" foam structures, homogenizing results and masking inherent formulation differences. The Foam Flash method, while introducing cyclic mechanical stress, is still a valuable tool—particularly for differentiating the foamability of high-foamers, ,in this specific case, however, Foam Flash resulted in similar profiles across all samples, making it less effective for distinguishing between these particular shampoo formulations.

Figures 1 and 2 illustrate these trends, showing the evolution of foam stability, bubble dynamics, and liquid drainage over time for both Sparging and Foam Flash method.

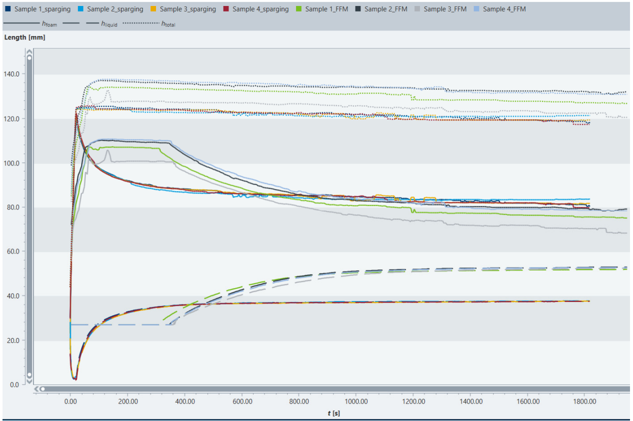

Figure 1: Foam height trends observed in Sparging and Foam Flash Method.

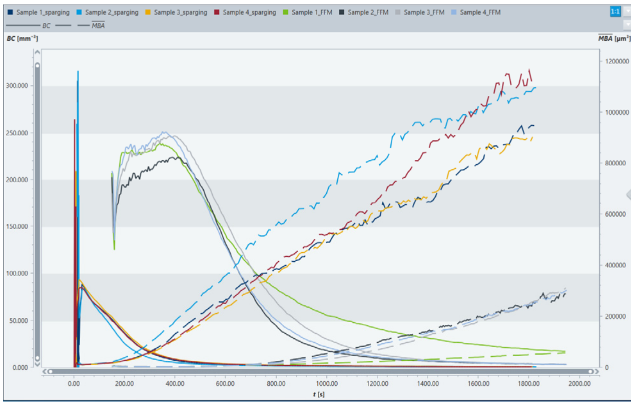

Figure 2: Comparison of foam structure using Sparging and Foam Flash method.

Adapted Foam Flash method

The Adapted Foam Flash method provided the most reliable differentiation among shampoo formulations. Sample 2 generated the highest foam, while Sample 3 produced the least. This distinction can be linked to variations in surfactant concentration and polymer additives within the formulations.

Bubble size distribution analysis indicated that Sample 3 initially exhibited the largest bubbles, indicating rapid initial foam expansion. Structural imaging at 200 seconds (160 seconds post-foaming) confirmed these trends: the foam in Sample 2 remained dense and uniform, whereas Sample 3 displayed visible coalescence. However, after 10 minutes, Sample 1 and 4 displayed the most stable foam structure, maintaining a uniform bubble size with minimal coalescence. This behavior suggests superior surfactant arrangement at the gas-liquid interface, reinforcing foam longevity.

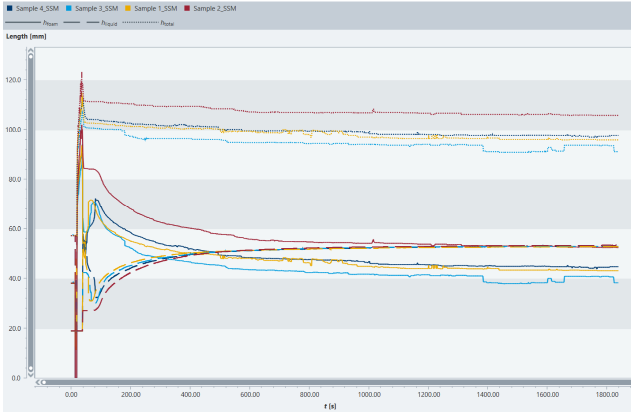

Figure 3: Comparison of foam heights using Adapted Foam Flash method.

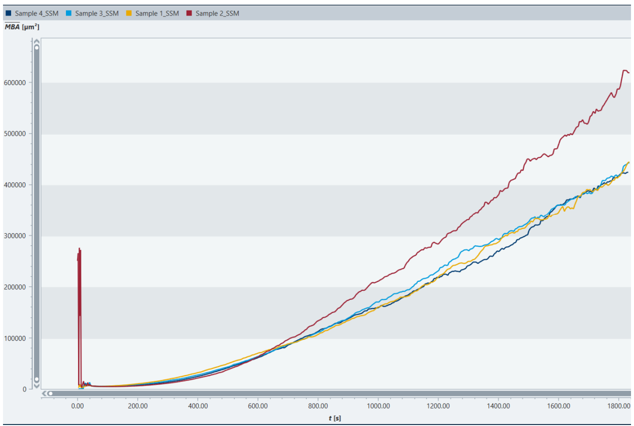

Figure 4: Comparison of MBA (=Mean Bubble Area) in µm² using Adapted Foam Flash method.

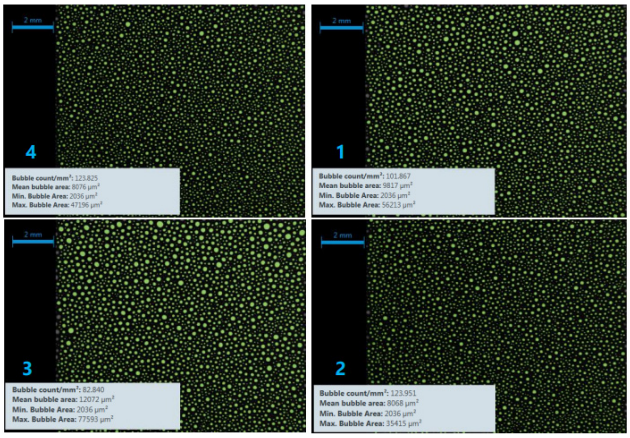

Figure 5: Comparison bubble structure images at exactly 200 s (160 s after foam generation) using Adapted Foam Flash method.

The Adapted Foam Flash protocol provided clear differentiation. Foam stability varied significantly across the samples, as shown in Figure 3. Sample 2 started with the lowest initial liquid volume and reached its plateau, indicating a fast drainage rate over the entire measurement period. However, at around 300 seconds, Sample 1 showed the highest drained liquid volume, followed by Samples 3, 4, and then 2, indicating sample 2 retained the most liquid in the foam during the initial time period. Bubble dynamics further highlighted disparities:

- Initial (0–5 minutes): Mean Bubble Area (MBA) followed Sample 3 > Sample 1 > Sample 4 ≈ Sample 2, indicating larger bubbles in Sample 3.
- Late-stage (10 minutes): MBA shifted to Sample 2 > Sample 3 > Sample 4 ≈ Sample 1, revealing dynamic bubble growth in Sample 2.
- Bubble Count: Sample 1 maintained the highest bubble density, reflecting fine, stable foam, while the foam in Sample 2 degraded into larger, heterogeneous bubbles.

These findings highlight the importance of selecting an appropriate measurement technique for foam characterization. The Adapted Foam Flash method emerges as the most effective approach for distinguishing formulation properties and ensuring reproducible results.

Conclusion

This study provides a comprehensive analysis of the foaming behavior of shampoo formulations, emphasizing the impact of measurement techniques on data interpretation. The Sparging method was effective in generating high foam volumes but lacked differentiation capability. The Foam Flash method, while leading to notable foam collapse in this study, offers valuable insights into foam stability under cyclic agitation and can be useful for applications where repeated stirring is relevant. The Adapted Foam Flash method emerged as the most suitable technique, offering clear distinctions between samples in terms of foam height, stability, and structure. The ability of Adapted Foam Flash to differentiate samples based on foam height, drainage, and bubble dynamics makes it ideal for R&D and quality control. This method enabled precise differentiation of foam properties.

Sample 2 exhibited the highest foam volume but suffered from instability due to rapid bubble coalescence, likely caused by insufficient polymeric stabilizers or excessive bubble merging. Sample 1 demonstrated a balance between foam stability and bubble uniformity, characteristics that align with premium product expectations and are attributed to optimal surfactant-polymer interactions. Sample 3 exhibited low foam height and experienced noticeable coalescence over time.

These findings have practical implications for formulation optimization, quality control, and consumer perception. Improving Sample 2's stability could be achieved by incorporating cationic polymers, amphoteric surfactants, or silicones to enhance foam longevity and improve interfacial film strength. The Adapted Foam Flash method in this case proves valuable as a routine quality control tool, replicating real-world usage conditions. Additionally, the correlation between fine, stable foam and premium sensory appeal suggests that formulation adjustments can be tailored to meet consumer expectations. This alignment between foam structure and consumer preference highlights opportunities for targeted marketing strategies and premium product positioning. Future studies could explore the influence of surfactant composition and additive interactions on foam characteristics, integrating visual representations of foam height trends, drainage curves, and bubble size distributions for enhanced comparative analysis.

Literature

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