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ONE-STOP HAIR CURE

80% of women agree that a 'good hair day' boosts their confidence, happiness, and sense of beauty. However, two-thirds are only 'sometimes happy' with their hair and seek better products without extra time or cost[1]. While social media increasingly shape grooming habits, rising disposal incomes and urbanization also influence the hair care industry. Alongside these trends, a segment of consumers searches for more sustainable ingredients, prompting brands owners to adapt their offering.

Formulators have been developing new products tailored to address various individual preferences and needs, such as specific to hair types, health, aesthetics (foamy, scents, etc.) or showcasing sustainability attributes. However, tailoring formulations is not as simple as switching one ingredient for another. Even the most basic shampoos are carefully choreographed formulations that perform a plethora of tasks all at the same time and quickly. From cleansing to depositing benefit agents, they aim to create a pleasant experience with a luscious feel, quickly lathering into an appealing foam that rinses off easily. Hence offering sustainable and high-performing versatile shampoo is a major challenge faced by the global hair care industry.

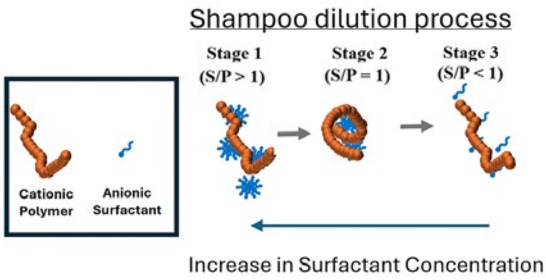
This trend towards personalization has led to over 19,000 new shampoos, hair treatments, and conditioners being launched every year for at least the last five years globally, according to Mintel GNPD data. The number of choices is overwhelming for the consumers and even more for the formulators who must find trade-offs and balance compatibility issues when selecting ingredients for new products. For a long time, they have sought ingredients to develop versatile platform formulations, supporting or helping enable quicker customization and simplified options and operations. To address this gap, an innovative, easy to use and multifunctional dual cationic dextran was introduced to the industry. On top of showcasing strong performance against a set of important criteria we will detail, it also presents a sustainable profile and is inherent ultimate biodegradable. Compared to the incumbent alternatives, dual cationic dextran is a step change in many dimensions:

- Liquid form simplifying formulation and ensuring high compatibility with other ingredients
- Effectiveness for most hair types and product formats
- Excellent consumer performance regarding hair appearance, combing of wet and dry hair, and hair health
- Advanced sustainability by being bio-based, inherent ultimate biodegradable, and dual action for material efficiency
- Foam boosting and increased lathering in surfactant-based formulations like shampoos
- A standalone rinse off conditioning polymer on its own without the aid of a conditioning additive

WHY DUAL CATIONIC DEXTRAN ENHANCES SHAMPOO EFFECTIVENESS

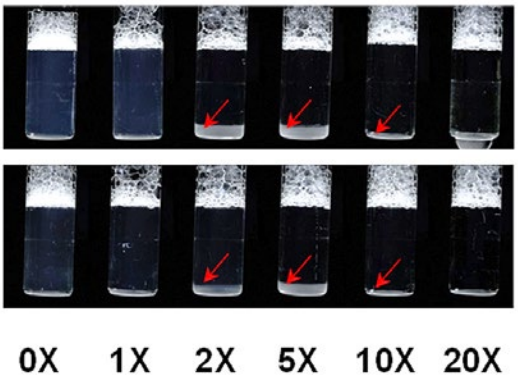
Shampoos usually contain more anionic (negatively charged) surfactants than cationic (positively charged) polymers as shown in **Figure 1**. Initially, these form "string of pearls" complexes during stage 1. When shampoo is diluted with water during the washing as represented in stage 2, the complexes break down, and new charge-balanced complexes form and precipitate. These hydrophobic complexes adhere to hair, allowing the cationic polymer – and any beneficial agents it carries, like silicones or fragrances – to deposit on the hair. During rinsing, further dilution reduces surfactant concentration below the critical

FIGURE 1



Schematic representation of the three dissolved states of oppositely charged surfactant/polymer (S/P is the charge ratio) complex in solution.

FIGURE 2



Photographs of model shampoos (Table 1) throughout dilution with deionized water. The undiluted shampoos are marked as 0×. The dilution factor is given below each image on a volume basis (1x, 2x, etc.) The cationic polymer is catGuar and the surfactant is SLES1EO/CapB in the upper panel and SLES3EO/CapB in the lower panel. During a dilution of 2X-5X, which mimics rinse off dilutions, the phase separated cationic polymer-surfactant complex is deposited at the bottom of the vial as shown by the red arrows. These precipitates, or coacervates, are responsible for entraining benefit agents that are deposited on hair.

TABLE 1

Model formulation for fundamental understanding of shampoos

Description	% active by wt	Examples
Primary Surfactant: Cleaning	9	SLES nEO SLS Sulfate Free Surfactants
Co-Surfactant: Foam Booster and Viscosity Builder	2	Cocamidopropyl Betaine Alkanolamide
Benefiting Oil	1	Silicone Coconut Oil Jojoba Oil Argan Oil
Deposition Aid Polymer	0.3	Dual cationic dextran CatGuar CatHEC Chitosan
Water	Balance	x

photos and graphics: Dow

micelle concentration (CMC), causing more dissociation. The remaining cationic polymer then binds directly to the negatively charged hair strands, completing the deposition process in stage 3[2] .

Incumbent cationic polymers like cationic guar (catGuar) or hydroxyethyl cellulose (catHEC) systems are rigid polymers that have a propensity for solid – liquid or liquid-liquid phase separation at concentrations relevant to formulation of rinse-off personal care products[3] . **Figure 2** shows this effect for a catGuar – surfactant complex when diluted in water.

Figure 3 shows that the same demonstration with dual cationic dextran – surfactant complexes exhibit a similar mechanism to incumbent cationic polymers (catGuar, catHEC). Traditional "charge-balanced complexes" are formed which phase separate and precipitate in the mid-range dilutions (2X-5X). In addition, however, dual cationic dextran formulations form blue turbid solutions as well. This marks a unique feature of cationic dextran polymers, offering a second channel of deposition for benefit agents. The particles in the blue turbid region have average particle diameters of 100 - 200 nm at total surfactant concentrations of 60 - 150 mM (**Figure 3b**) as measured by liquid-phase transmission electron microscope in situ[3]. This was also measured and confirmed by dynamic light scattering[3]. We hypothesize that the blue turbid complexes contain multiple chains of dual cationic dextran with surfactants because these diameters are much larger than the size of surfactant micelles measured in the absence of dual cationic dextran. **Figure 3c** shows the evidence that these unique nanostructures in the blue turbid phase are surface active and can drive deposition. Surface activity of nanocomplexes was established by Quartz- Crystal Microbalance with Dissipation (QCM-D). Silica was chosen as it mimics the zeta-potential (-30 mV) and hydrophilicity of the hair fibers. Delta frequency shows the adsorption kinetics and washout processes. These results suggest concentration-dependent deposition even in an undiluted shampoo (0X Dilution) with this new "surface active nanostructure".

This indicates that formulations with dual cationic dextran deposit benefit agents both by (1) the blue-phase, surface-active nanostructures and (2) the traditional charge-balanced complexes. This contrasts with the deposition behavior for other cationic polymers (catHEC, catGuar), where the bulk of deposition takes place only by the traditional charge-balanced complexes.

The dual-action deposition hypothesis was tested by adding a silicone oil benefiting agent to the model formulation in Table 1. The shampoo dilutions confirmed the deposition of silicone oil through blue-phase, surface-active nanostructures at undiluted stage. This is shown by the aggregation of silicone on the glass vial between 0-40X dilution. Deposition through the traditional coacervation of the charge-balanced complexes also occurred in mid-range dilutions (**Figure 4**). Note that are model formulations whereas in a commercial shampoo formulation these nanocomplex will not precipitate out on the bottle as the dynamics are slowed down by rheology modifiers for the shelf life of the product.

Based on the QCM-D results, we hypothesized that significantly higher levels of silicone would be deposited onto hair than incumbent technologies due to the dual action of the new surface-active nanostructures in addition to the traditional charge-balanced complexes. This was tested in a formulation representative of commercial shampoos

FIGURE 3

a) Photographs of model shampoos throughout dilution with deionized water. The undiluted shampoos (marked as 0×) contained 9 wt% SLES 1EO, 2 wt% CapB, and 0.3 wt% dual cationic dextran. The dilution factor is given below each image on a volume basis.
b) Undiluted shampoo imaged with liquid phase TEM to show the 200 nm nanocomplex morphology.
c) Surface activity of nanocomplexes established by Quartz-Crystal Microbalance with Dissipation (QCM-D). The y axis represents delta frequency which is equivalent to show the mass adsorption kinetics and washout processes for the adsorption of a dual cationic dextran – SLES/CapB nanocomplex as depicted as the time dependence of the shift of the central frequency.

CD-2 polymer exhibits a second, unique mode for benefit agent deposition, thus increasing effectiveness and efficiency

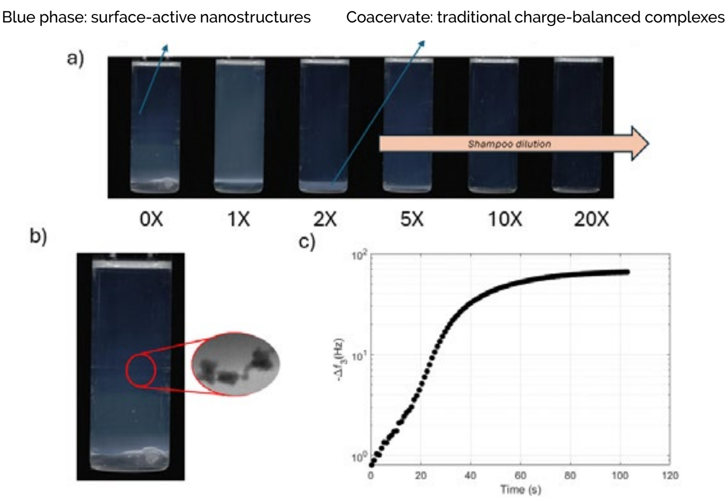


FIGURE 4

Photographs of model shampoos throughout dilution with deionized water. The undiluted shampoos (marked as 0×) contained 9 wt% SLES 1EO, 2 wt% CapB, 1 wt% silicone and 0.3 wt% dual cationic dextran. The dilution factor is given above each image on a volume basis.

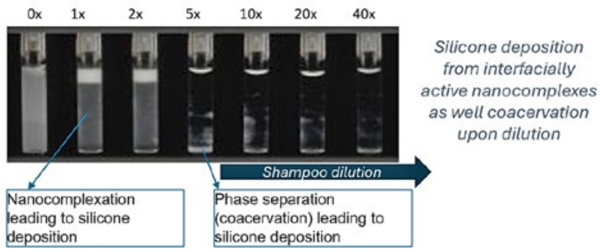


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TABLE 2

Shampoo ingredients with dual cationic dextran.

Phase	Function	Ingredient name	Wt. %
A	Deionized Water	Water/aqua	Balance
	Primary Surfactant	Sodium Laureth Sulfate (SLES 1EO)	9
	Cationic Polymer	Dual cationic dextran or catGuar	0.3
	Chelating agent	Tetrasodium EDTA	0.2
B	Rheology Modifier	PEG-150 Pentaerythrityl Tetrastearate	1
	Foam Booster	Cocamide MEA	1
C	Secondary Surfactant	Cocamidopropyl Betaine	2
D	Silicone Emulsion	Amodimethicone (and) C11-15 Alketh-12 (and) C11-15 Aketh-7	1
	Preservative	Phenoxyethanol and Ethyhexyglycerin	0.5

for damaged hair (Table 2), one of the more challenging applications.

After shampooing, X-ray photoelectron spectroscopy (XPS) was used to quantify silicone deposition onto the tresses (**Figure 5**). Consistent with our hypothesis, shampoos formulated with dual cationic dextran deposited significantly more silicone onto the surface of hair than catGuar.

The tribological performance on hair was tested in a formulation representative of commercial shampoos for damaged hair (Table 2), the most challenging application (same as Figure 5, which measured silicone deposition on damaged hair). **Figure 6** (upper panel) demonstrates that dual cationic dextran offers significant tribological benefits in terms of lower coefficient of friction- COF (smoothness or lubricity on hair surface) values at the same polymer use level. Similarly, **Figure 6** (lower panel) shows significant lower dry and wet combing load (inter-fiber friction and detangling) measured on damaged hair with dual cationic dextran compared to other cationic polymers. This indicates efficient deposition of silicone to offer a lubricated surface.

The project addresses consumer trends and performance to have a natural and good look. The introduction of dual cationic dextran offers a versatile and sustainable option for hair care products while supporting personalized formulations.

FIGURE 5

Dual cationic dextran deposits more silicone on damaged hair than catGuar (Table 2 formulation). The mole percentage (mol%) of silicon (Si) detected on the surface of Caucasian damaged hair washed with the shampoos as measured via X-Ray photoelectron spectroscopy (XPS).

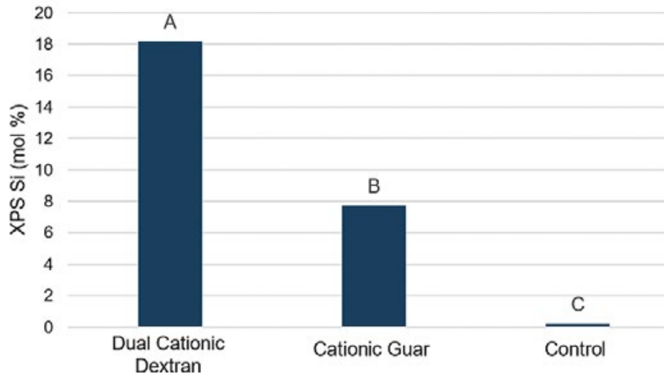
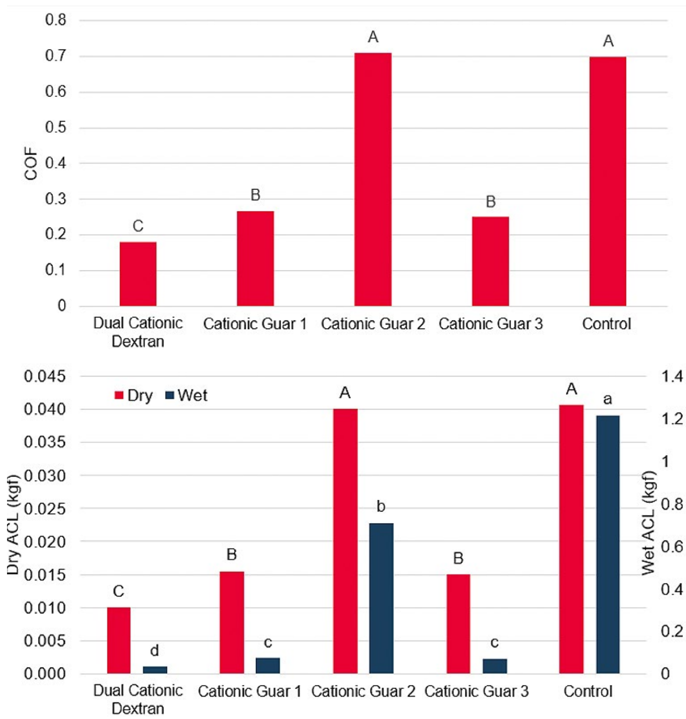


FIGURE 6

Dual cationic dextran significantly reduces friction (COF) and detangling force (ACL) compared to various cationic guars. Different letters show a statistical difference at 95% confidence. Shampoo was prepared based on Table 2.



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