J. Cosmet. Sci., 69, 397–405 (September/October 2018)

Applying Light Scattering Theory to Measure Rinsability of Hair Conditioners

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Synopsis

As the world is striving to become more sustainable, water consumption is considered an important area of focus, especially in those regions with limited freshwater resources. To address this issue, the personal care industry has identified faster rinsability of hair care products as a way to contribute to water preservation efforts. To understand rinsability, analysis of colloidal systems and an investigation into concentration of whole products in water is critical. However, particle size and particle migration in colloidal systems require the use of specialized optical methods. In previous research, we learned that conditioners form colloidal particles rather than true solutions during the rinsing process, and hence cannot be studied using ultraviolet-visible spectroscopy. Through this study, a Turbiscan instrument was determined to have the capability of measuring multiple light scattering given off by conditioner systems. Therefore, measurements of light scatter from a series of diluted conditioner dispersions can be used to generate a calibration curve to calculate unknown concentrations of conditioner in rinse water at different rinsing time intervals. The newly developed test method was successfully applied to determine the rinsability of various conditioner formulations on both virgin and bleached hair. The findings of our study will be presented here.

INTRODUCTION

Water scarcity is a paramount concern as it was once considered to be a renewable resource, and is now gradually becoming a non-renewable resource. Globally, there is only 3.5% of available freshwater, relative to salt water, to meet the demand of an ever growing global population (1). Water use has been growing globally at more than twice the rate of population increase in the last century. As a result, an increasing number of regions are reaching the limit at which water services can be sustainably delivered, especially in arid regions. Currently, 1/5 of the global population, about 1.5 billion people, live in areas where water is physically scarce. By 2025, about 1.8 billion people are expected to live in areas with absolute water scarcity (2). As water scarcity increases across developing regions, manufacturers of rinse-off beauty and personal care products will face challenges in these regions where most of the potential growth in sales in the future is expected.

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To fight the global water crisis, we see more and more water conservation efforts being undertaken by consumers, including cutting down on the use of water in personal grooming practices. Consumer awareness of this issue is on the rise, and water conservation is becoming a top priority for them. As consumers are cutting back on their water usage, they are expecting personal care brands to do the same (3). Sustainability is becoming more and more integral to the business model of consumer goods companies as it is becoming increasingly important in the minds of consumers. Essentially, consumers need products that require less rinsing without compromising the performance of the product. In an effort to reduce the water footprint in the personal care industry, a few companies have started to develop water-smart products with a primary focus on "faster rinsing" claims with the aim of conserving water. However, there is currently no method available to describe the rinsing behavior of products. To live a life of responsible consumption and production, a method is needed to quantify the rinsability of products to prove that they do, in fact, rinse out faster than your conventional shower product.

Rinsability is a term coined by the industry to describe the rinsing behavior of personal care products. It is not a new concept. Many companies have developed their own rinsability method by focusing on hair attributes such as wet friction or bending force. However, these methods aim to only focus on the hair itself. Although this is a good starting point, they fail to analyze the product as it washes off the hair. For this reason, studies of the rinsed water have been conducted, using conditioner systems, to describe the rinsing performance of such systems and to approximate what ultimately remains on the hair surface.

MATERIALS AND METHODS

Although conditioners are generally composed of 80–90% water, the remaining percentage is composed of miscellaneous ingredients that are insoluble in water, thus creating a colloidal system. We can take advantage of the colloidal system to approximate the concentration of product that is washed off using properties of light scattering. Light scattering is simply the redirection of light; it happens when energy waves are forced to deviate from a straight path because of imperfections in a given medium (4). Light scatter can be used to approximate unknown amounts of conditioner material in water by the Beer–Lambert law. The Beer–Lambert law, or $A = \varepsilon_m C \ell$, is a linear relationship between absorbance and concentration. It is normally used for samples that absorb light at a particular wavelength. However, because conditioner materials mainly scatter light, optical density is used instead of absorbance. Optical density is not a measure of absorbance, but rather a measure of light scattered by particle suspension which manifests itself as absorbance. As visible light passes through a suspension, the light is scattered. Greater scatter indicates more particles present. This method is often used in biological related fields to study bacteria that are often colorless and do not scatter light (5). The optical density is represented in terms of transmittance. Transmittance is inversely proportional to absorbance, given by the Beer–Lambert Law. Traditionally, spectrophotometers are used to measure absorbance. However, they are not optimized for light scattering measurements. Spectrophotometers commonly result in differences in measurements between scans and between instruments (6). Because of the nature of the samples, the Turbiscan from Formulaction was used for this study. The Turbiscan uses multiple light scattering theory associated to a vertical scanning head, enabling it to measure particles of varying size and movement. The Turbiscan is used here to obtain transmittance values for our samples (7).

In this experiment, four simple conditioning systems were studied (refer to Table I): one based on a behenyl quat, a second based on di-behenyl quat, a third based on an amine salt as the conditioning active, and the fourth using a non-ionic emulsifier as the negative control system. The rinsing behaviors of the four conditioners were evaluated using two different hair types, namely European bleached and European virgin hair, enabling us to study the surface interactions between the hair types and the conditioner systems.

In this study, three hair tresses were used per hair type for each conditioner treatment. Each tress was individually cleansed with a basic shampoo then rinsed. Following cleansing, each tress was treated with 2 g of the respective conditioner treatment, and then subjected to an automated rinsing system. The rinsed water was collected every 5 s, starting at 0 s. The Turbiscan was used to measure each sample to obtain a transmittance value. A calibration curve was subsequently established for each conditioner system to determine an equation of the line, which would then be used in later analysis to correlate optical density to concentration. To establish the rinsability curve, each curve was normalized and initialized starting at 0 s. Each subsequent point is a percentage decrease in concentration with respect to the initial point to determine how much conditioner is left on the hair with respect to the initial amount of product applied to each hair tress (2 g). Concentration is presented in terms of percentage and is graphed as a function of rinsing time in seconds.

RESULTS AND DISCUSSION

Figure 1 depicts the calibration curves for the four conditioners. All conditioners exhibited a linear correlation between concentration and optical density. The variation in the slopes can be attributed to the solubility of the conditioner products in water. It is observed that the absorbance value of the rinsed solution mainly depends on the degree of transparency of the solution, or the turbidity. The more turbid the solution, the higher the absorbance value. Therefore, absorbance can be used as an indicator of the solubility of the tested conditioner in water. As a result, the slope of the calibration line is an indication of changes in solubility of the conditioner with concentration. The calibration curves will serve as a basis for the rinsability of the conditioners.

Table I
Conditioning Formulations

Ingredients	Conditioner A: behenyl quat (%)	Conditioner B: di-behenyl quat (%)	Conditioner C: amine salt (%)	Conditioner D: non-ionic emulsifier (%)
Part A				
D.I. Water	Q.S.	Q.S.	Q.S.	Q.S.
Part B				
Conditioning active	1.50	1.50	1.50	1.50
Fatty alcohol	4.50	4.50	4.50	4.50
Part C				
Preservative	0.10	0.10	0.10	0.10

All formulations based on 1.5% active conditioning active in the systems and neutralized to pH 4.0–4.5.

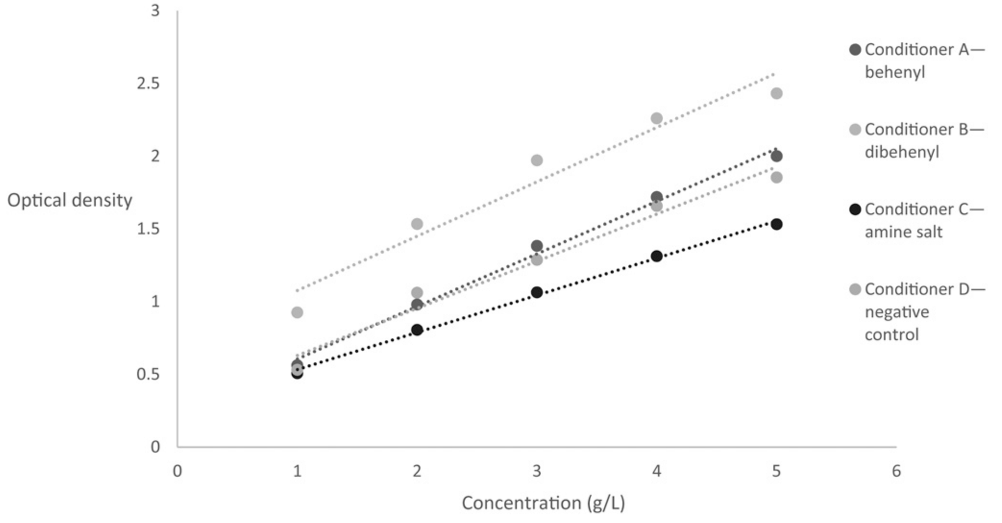

Figure 1. Calibration curves for Conditioner Systems of with Different Chemistries.

RINSABILITY PROFILE OF VARIOUS CONDITIONERS

The data on the rinsability profile of the different conditioners on bleached hair is depicted in Figure 2. One can observe that Conditioner A, based on the behenyl quat, washes off the hair quickly initially, but then plateaus the quickest compared with the other conditioning systems, indicating that more residual product remains on the hair. This can be attributed to the cationic nature of this material and its long alkyl chain and substantivity to the negatively charged surface of the bleached damaged hair. Contrary to Conditioner A, Conditioner B, based on the di-behenyl quat, rinsed out more slowly with much less residual product remaining after 30 s of rinsing. Conditioner C, based on the amine salt, took the longest to rinse out overall of all the conditioners. We can hypothesize that

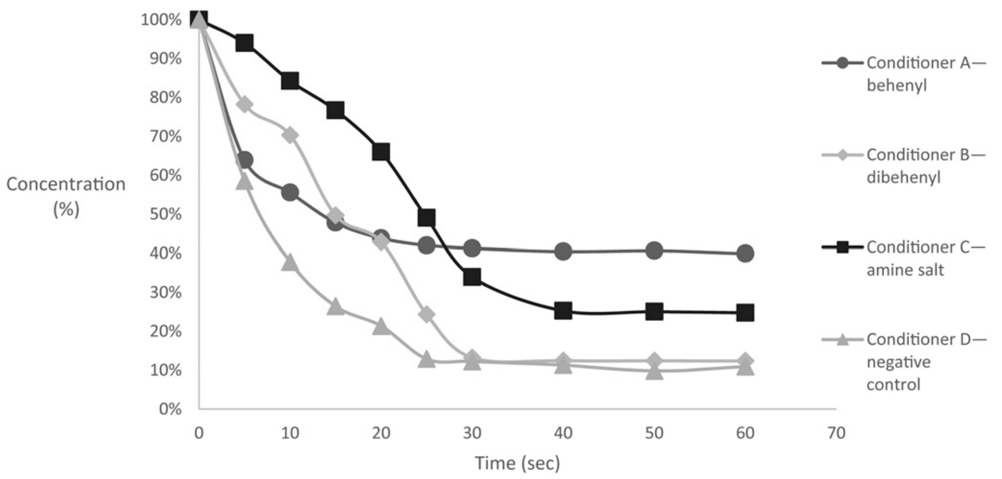

Figure 2. The Rinsing Behavior of Conditioner Systems on European Bleached Hair as a Function of Time.

this could be attributed to the material's poor water solubility. It is also worth noting that Conditioner C had more conditioner material left on the hair compared with conditioners B (the di-Behenyl quat) and D (the non-ionic). Conditioner D, our non-ionic emulsifying negative control system, as expected, rinsed out very quickly, leaving very little product on the hair after 60 s. As it can be predicted, this system would not exhibit any substantivity to the bleached hair surface, and therefore would be expected to rinse out quickly with little to no residual product left behind.

The data on the rinsability of the conditioners on virgin hair are displayed in Figure 3. Some similarities are observed in the rinsing profile of some of the conditioner systems, namely Conditioners C and D on both bleached and virgin hair, as exhibited in Figures 2 and 3. Conditioner C, the amine salt, once again took the longest to rinse out of virgin hair before it plateaued, thereby exhibiting a similar profile to its performance on bleached hair. However, on virgin hair, more residual conditioner C material was left on the hair when compared with the other systems. Conditioner D, our negative control, once again exhibited similar rinsing patterns as it did in its performance on bleached hair, by rinsing out the quickest and leaving very little to no residual material on the hair surface as would be expected. Conditioner A and B, the behenyl and di-behenyl quat system respectively, exhibited similar rinsing profiles on virgin hair, contrary to their performance on bleached hair. Both conditioner systems had less affinity for or were less substantive to virgin hair, thereby both products rinsed out quickly, but with Conditioner A having much less residual product remaining on the hair as compared with its rinsing profile on bleached hair.

TIME CONSTANT RELATIVE TO RESIDUAL CONDITIONER MATERIALS

To further describe the pattern in these rinsing curves, a mathematical representation of the percent time constant and percent residual material is illustrated in Figures 4 and 5,

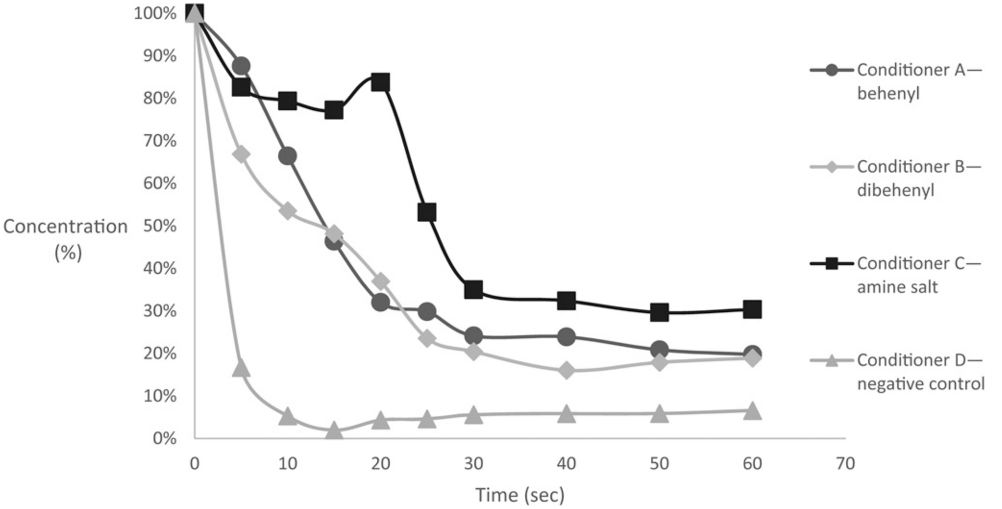

Figure 3. The Rinsing Behavior of Conditioner Systems on European Virgin Hair as a Function of Time.

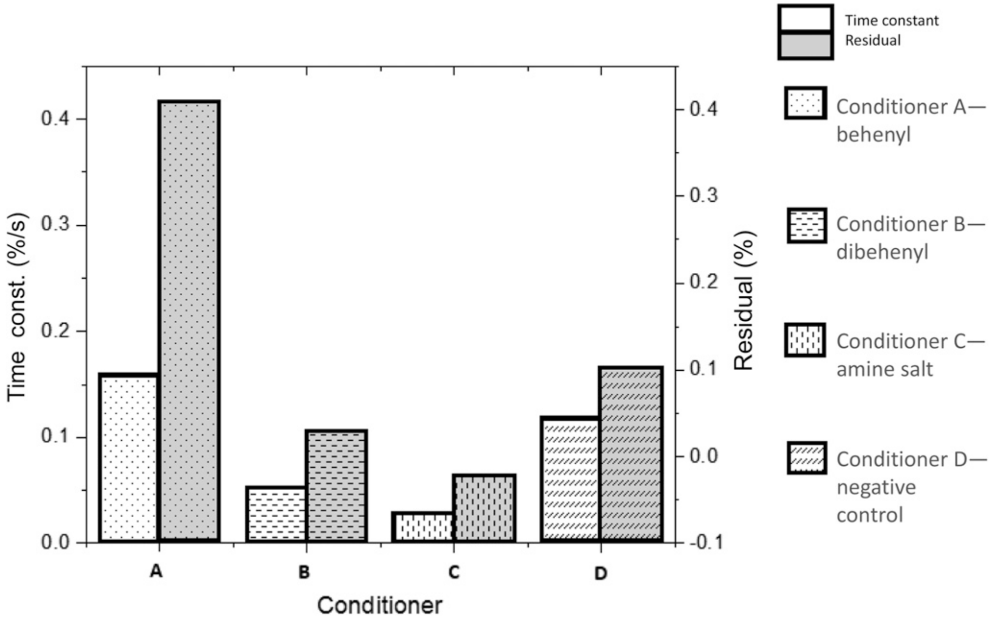

Figure 4. Time constant of slopes of the curves as a function of remaining residual conditioner product left on European bleached hair.

representing the rinsing behaviors of the tested conditioners seen previously for bleached hair and virgin hair in Figures 2 and 3, respectively. The time constants (%) were calculated based on slope and time for each rinsing curve, indicated by the first bar in Figures 4 and 5. Furthermore, percent residue of conditioner product left on the hair was also

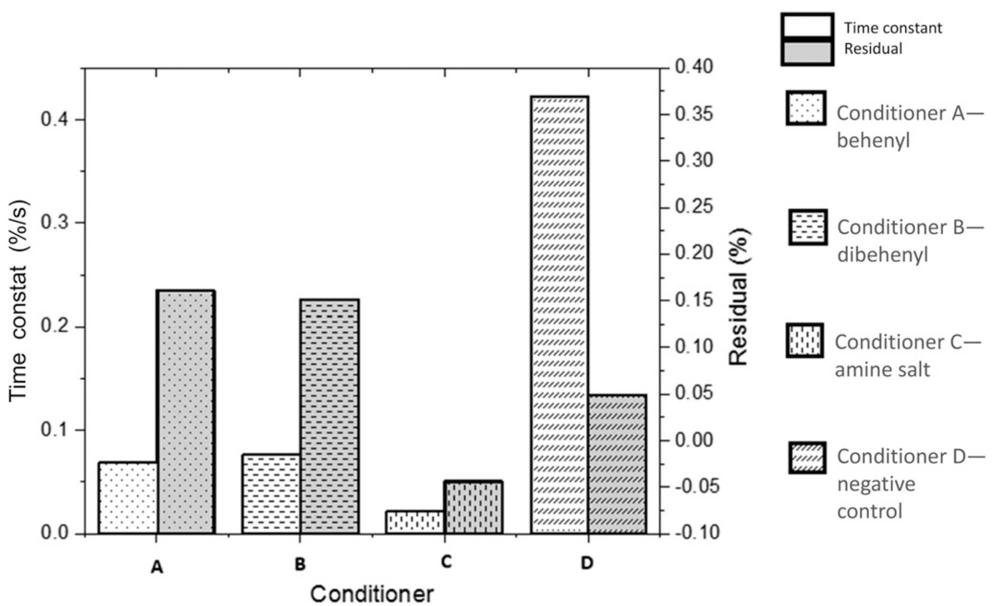

Figure 5. Time constant of slopes of the curves as a function of remaining residual conditioner product left on European virgin hair.

modeled as indicated by the second bar in the figures. For time constant, the higher the value of the bar, the faster the conditioner rinses off. For the residual material, the higher the value of the bar, the more residual material left on the hair after rinsing relative to the time constant.

As seen in Figure 4, Conditioners A and D exhibit comparable time constant values on bleached hair, as indicated by the steepness of their slope. Yet, relative to their residual bar, Conditioner A has a much higher residual value compared with Conditioner D, indicating that although both conditioners rinse out quickly, Conditioner A has much more conditioner material remaining on the hair because of its substantivity. Conditioner C displays the smallest time constant value, demonstrating that Conditioner C had the longest rinse out time. Its residual component with respect to its time constant indicates that Conditioner C has a high amount of residual material left behind. Thus, although Conditioner C took the longest time to rinse out compared with the other systems, it still has a considerable amount of material left on the hair surface.

Similar analysis can be performed on virgin hair. As depicted in Figure 5, Conditioner D, the negative control, has the highest value for the time constant and the lowest residual value relative to the time constant, indicative of a product that rinses out faster, leaving very little material on the hair compared with the other conditioner systems. Conditioners A and B have similar values time constant and residual values, indicating that these materials have similar rinsing performance on virgin hair. Conditioner C has the smallest value for the time constant, indicating it took the longest to rinse out. Its residual component with respect to its time constant indicates it still has a high amount of residual material left on the hair relative to the other conditioner systems.

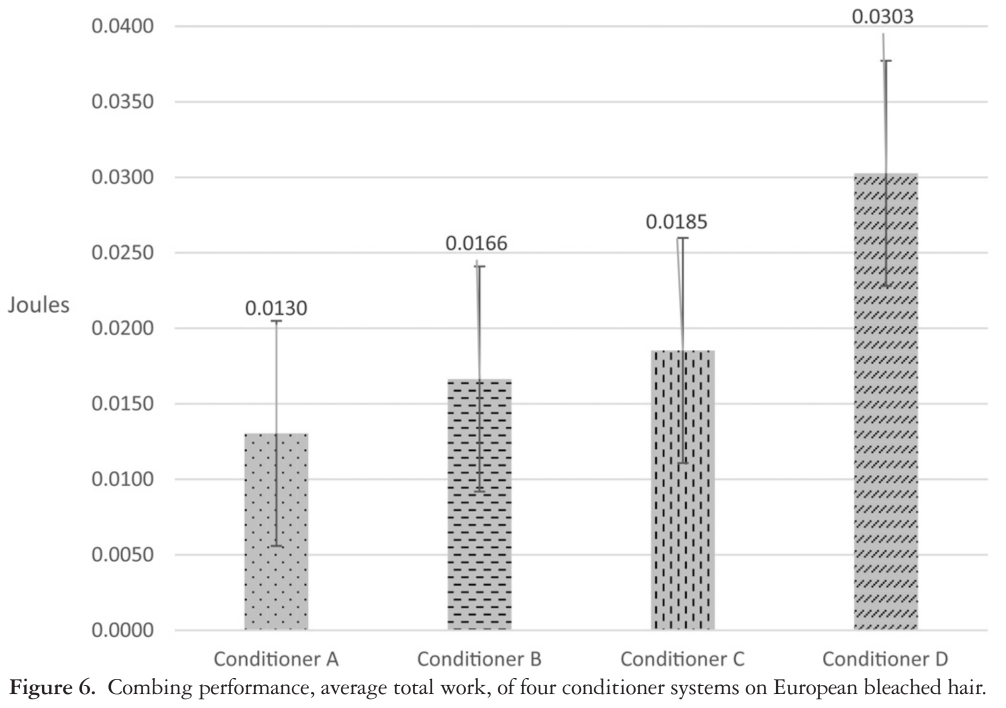

Figure 6. Combing performance, average total work, of four conditioner systems on European bleached hair.

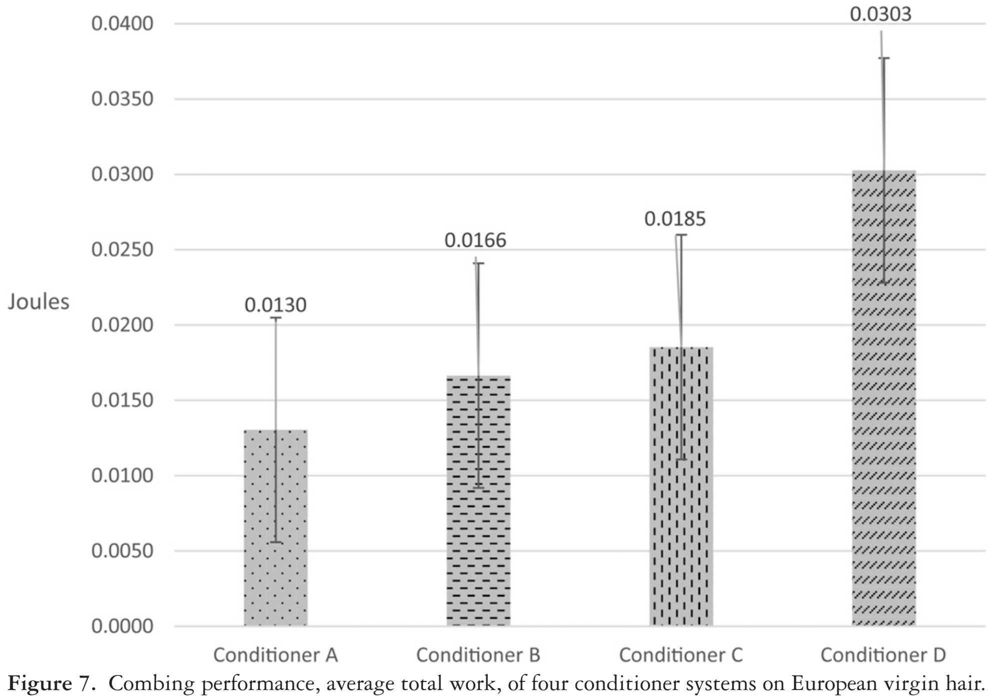

Figure 7. Combing performance, average total work, of four conditioner systems on European virgin hair.

COMBING PERFORMANCE

Once the rinsability profile of the different conditioner systems had been established, it was important to compare against their conditioning/combing performance. Figures 6 and 7 depict the absolute values of the average combing force of the treated and rinsed bleached and virgin hair tresses as related to the average total work performed for the four conditioner systems tested in the rinsability study. Notice in both figures, Conditioner D has the highest combing force, indicating poor conditioning performance compared with the other conditioners. This correlates well to the rinsing data seen previously as Conditioner D is our negative control non-ionic system, and it is expected to not condition the hair as it's not substantive and thus won't deposit, and thus will rinse out the quickest. However, notice that Conditioners A, B, and C virtually exhibit comparable combing performance on both bleached and virgin hair. No statistical difference in combing force is seen among these three conditioner systems, but yet there are significant differences in their rinsing behaviors which can be attributed to their chemistry, confirming the introductory statement that studying hair surface attributes alone such as combing and friction is not sufficient to understand how a product behaves in terms of rinsability. This new rinsability test method confirms that subtle differences can be distinguished in the rinsing profile of different product chemistries.

CONCLUSION

A quick and simple optical method has been established and applied to quantitatively measure the rinsability of conditioner systems on different hair types. Using the Beer–Lambert relationship, non-absorbing particles can be measured with light scattering techniques to determine concentration based on optical density. This method can be applied to determine the rinsability of various conditioner systems with varying chemistries. Future experiments will include studying more complex systems, commercial conditioners, 2-in-1s and shampoo systems. In addition, whole-head salon studies will be conducted in the hopes of correlating the instrumental rinsing data to consumer perceivable data. Last, continued development includes plans to correlate wet frictional data to the rinsing data.

ACKNOWLEDGMENTS

The authors would like to thank the Croda R&D team and Research Director Mr. Abel Pereira for their contribution and continued support on this project.

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