Particle Size Determination of Mineral-Based Sunscreens: A Complex Analytical Application

Introduction

Mineral-based sunscreens have gained popularity due to their excellent ability to scatter ultraviolet (UV) rays without causing photo-induced skin irritation from chemical-based sunscreens.

Of the 18 U.S. Food and Drug Administration (FDA) approved active ingredients for sunscreen drug products (per 21CFR Part 352), only two are mineral based. Zinc oxide (ZnO), in particular, outperforms its counterpart titanium dioxide. Zinc oxide remains stable at high temperature and in neutral pH, covers a broad spectrum of UV radiation, and is even mildly antibacterial [1].

The safety and effectiveness of zinc oxide, however, is size dependent. Zinc oxide in micrometer size range offers lower Sun Protection Factor (SPF) compared to its nanometer sized equivalent [2]. Micron sized ZnO also has the tendency to leave a layer of chalky whiteness on the skin, decreasing its aesthetic appeal for the consumers. Zinc oxide particles of 200 nanometers or smaller are virtually transparent [3], but nanoparticles are generally not favored due to the possibility of particle penetration on intact skin. As zinc oxide particle sizes decreases, the need to coat ZnO with materials such as silicones or fatty acids increase. Coating aids in particle dispersion and creates a barrier for particle-skin interaction upon application. The choice of additives can either minimize or exacerbate particle agglomeration, influencing the shelf life of sunscreen products.

Formulation is a balancing act. For this reason, it is important to monitor the particle size of both active and inactive ingredients of sunscreen to maintain its intended efficacy and safety, while preventing the active ingredient from penetrating deep into the skin.

Regulatory Discussion

The U.S. FDA has not definitively stated if micronized particles are safer than nanoparticles in sunscreens or other cosmetic products. In their final Guidance for Industry released in 2016 [4], FDA simply recommends testing for particle size and for chronic exposure. The European Commission is more thorough with this respect. According to EC recommendation, "nanomaterial" means 50% or more of the particles with one or more external dimension within 1 nm to 100 nm range in number size distribution [5]. EC further recommends that, as a minimum, the particle size of both raw materials and final formulation must be assessed to identify batch-to-batch variation. To evaluate size parameter of sunscreen, more than one method must be obtained (e.g. dynamic light scattering, nanoparticle tracking analysis (NTA), laser diffraction, imaging, etc). However, the debate of nanomaterial safety on sunscreen (or any cosmetics) remains inconclusive.

Materials and Method

Three over-the-counter zinc oxide sunscreens were purchased and analyzed using Partica LA-960V2 Laser Diffraction Particle Size Analyzer. A standard 15 mL fraction cell accessory fitted with a magnetic stir bar was chosen for this experiment.

Sunscreen A is an expired equivalent of Sunscreen B (see Figure 1). Sunscreen A appears be "watery." Sunscreen B feels more viscous when rubbed against two fingers. Sunscreen C is from a different brand and has a creamier texture but all three sunscreens are water-resistant, oil-based formulations with "non-nano" zinc oxide claim on the bottle.

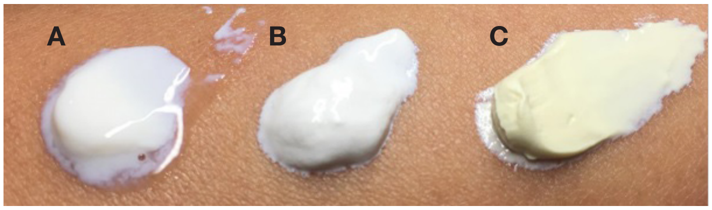

Figure 1. Sunscreen A is an expired version of B; Sunscreen C is from a different brand. All of the samples selected in this experiment are oil-based.

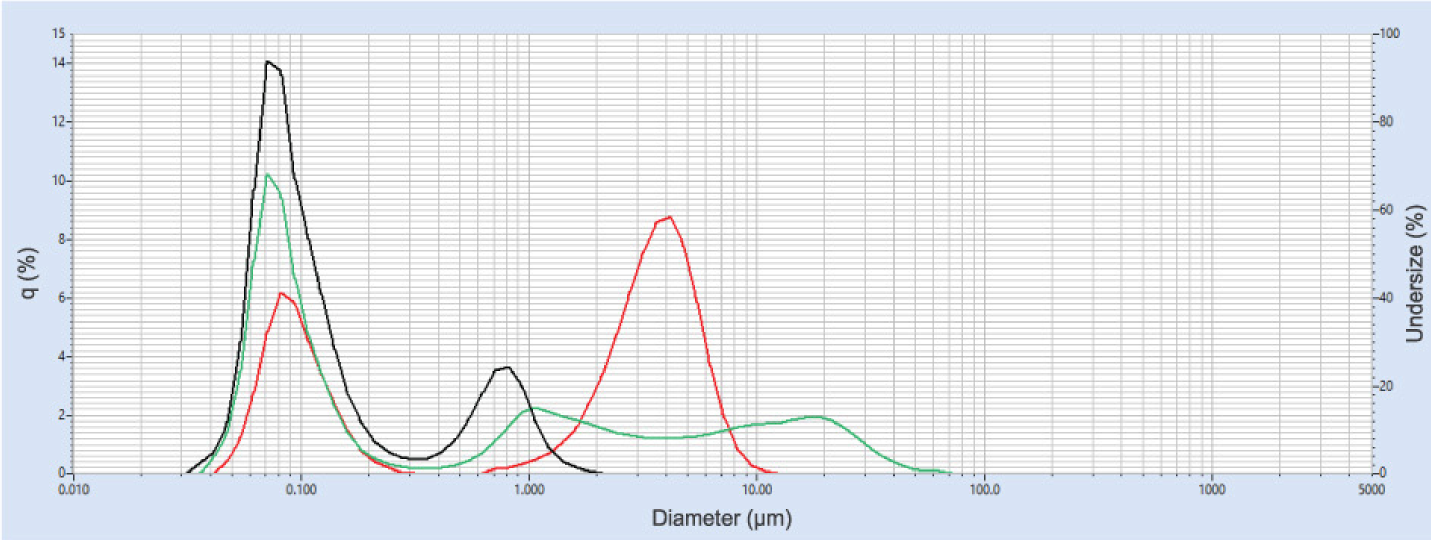

Figure 2. Each commercially available ZnO sunscreen is analyzed in triplicates to yield an average. Expired sunscreen in red demonstrate a clear separation of phases as seen by two distinct peaks.

Prior to analysis, each sample was minimally pre-dispersed with mineral spirits in a beaker so that the sample is diluted enough to be added to the fraction cell drop-by-drop with a plastic pipette until an appropriate laser transmission value is reached. The following analytical test method was used to collect measurements:

Refractive Index: 2.00 | Imaginary (absorption): 0.1i
Dispersant fluid – Mineral Spirits
Sample data acquisition times: 50000

Results and Discussion

Sunscreen A (**red**) displays two separate peaks with a Dv50 of 90 nm for the fine and Dv50 of 3.76 μm for the coarse. This distribution profile is an indicator of phase separation where two distinct populations of constituents are formed. This is typical of an unstable dispersion system. In comparison to A, Sunscreen B (**black**) has a fine peak (Dv50 = 80 nm) and another bimodal peak (Dv50 of 1.35 μm and 12.51 μm). Sunscreen B is cross-examined using optical microscopy where the lower size detection limit is restricted by the wavelength of visible light at 0.5 μm (Figure 3). While the image cannot verify the existence of nanoparticles, it confirms the bimodality above the 300 nm region.

In addition, the image also demonstrates the presence of particle agglomerations as big as 20 μm. Lastly, Sunscreen C (**green**) also shows a bimodal distribution (Dv50 of 80 nm and 0.76 μm). All three samples consistently exhibit peaks located between 30 nm to 300 nm range. This overlay may be where the active ingredient, zinc oxide, resides whereas the inactive components of the formulation are those above 300 nm.

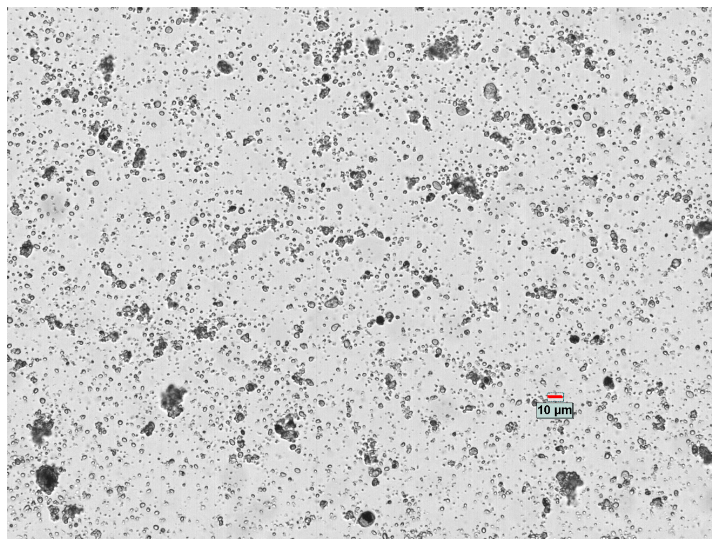

Figure 3. Sunscreen B image examined under optical microscope.

Note that laser diffraction technique reports particle size in its spherical equivalent diameter and in volume-based distribution. When the LA-960V2 software converts mathematically from volume to number, all three samples have more than 50% of particles smaller than 100 nm. Per EC regulation, these commercially available samples would all be considered as "nanomaterials." In this case, we recommend utilizing orthogonal technique such as the NTA to fulfill the requirements set out by EC.

Conclusion

This study demonstrates that Partica LA-960V2 Laser Diffraction Particle Size Analyzer is useful for characterizing zinc oxide particles as well as other inactive ingredients in a sunscreen formulation. The LA-960V2 is also a good screening tool for monitoring nanomaterials. While the FDA has not set out the absolute lower size limit for a sunscreen to be considered a nanomaterial, these products would be classified as such in the EU. This change in classification emphasizes the importance of monitoring particle size to maximize SPF, while ensuring the product steers clear from potential safety concerns.

References

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