Revisiting human skin, sunscreen films and protection performance

Can we create the ideal high performance sunscreen?

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The continuing rise of skin cancer rates in most countries calls for an extended effort. In terms of protection, one of the key factors continues to be the application of sunscreens. Here, raising compliance and performance of sunscreen usage remains the goal for the future, but often these two directions contradict each other. On the other hand, a current sunscreen would offer much more performance2 if human skin wasn’t that wrinkly, as it forces the sunscreen into very irregular films and strongly reduces the ‘protection performance’

Whilst this phenomenon of decreasing the performance has been known for more than 2 decades3, it is not very well understood how a sunscreen film forms and behaves on skin in microscopic detail – a necessary knowledge before one can create the “ideal high performance product”.

DSM therefore analyzed the sunscreen application process in detail and separated it into 3 phases:

1. application phase, 2. post-application phase, 3. resting phase.

Firstly, the application phase is controlled by a lot of externally applied periodic shear, whilst during the post-application phase internal forces make the semi-solid material flow. Finally, in the resting phase no flow happens at all. The sunscreen flow is driven by surface tension gradients, arising from forced irregular film geometries and concentration differences, which are caused by the evaporation of water or other solvents. During this phase, the rheological behavior of the semi dried sunscreen is thought to be crucial.

To achieve a high performing skin “coating”, it is desirable to have a spatially evenly distributed film thickness and follow exactly the profile of the skin with a constant thickness: a situation very much similar to paint coatings on rough substrates4. As a lot of effort is needed to create such a film, it would be wise to know before starting if such an ideal geometry had any chance to survive the internal forces driven flow; properties that such a film needs to bear. Otherwise it simply converts back to the much less favorable situation: a smooth upper surface with fully filled up wrinkles. This is exactly the regular scenario of how current sunscreens tend to behave. However, what is not understood, is whether the sunscreen flows into the fine lines during or after the active application phase.

We revisited ‘skin roughness’ profiles, analyzed the principle geometrical patterns of human skin and built this into a model. We measured the rheological behavior of dried sunscreen films and modeled the flow behavior of the post application phase in-silico on a model substrate with a “wrinkle”. The model could apply different film thicknesses and sunscreen material properties (e.g. rheology and surface tension). A surprising and encouraging endpoint for the flow was discovered: even a sunscreen with rheological properties that are easy to flow, would not move entirely into the wrinkle from the ideal film geometry starting point. We further evaluated whether Marangoni forces, caused by surface tension gradients, would help us to reverse an irregular film by “drawing” material out of the wrinkle. Marangoni forces can originate due evaporation of water or other solvents.

From the investigations we could overall conclude that the performance of a sunscreen is made during the application phase and little will change during flow afterwards. That lead us to formulate a very simple model which makes a lot of puzzling in-vitro and in-vivo SPF measurement experiences easier to understand. Some of the overall results will be presented in short ‘flow movies’ with narration of the key findings DSM discovered during these investigations.

Literature