Mathematical Model for TEWL Change during Tape Stripping of the Stratum Corneum

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Stratum Corneum Stripping

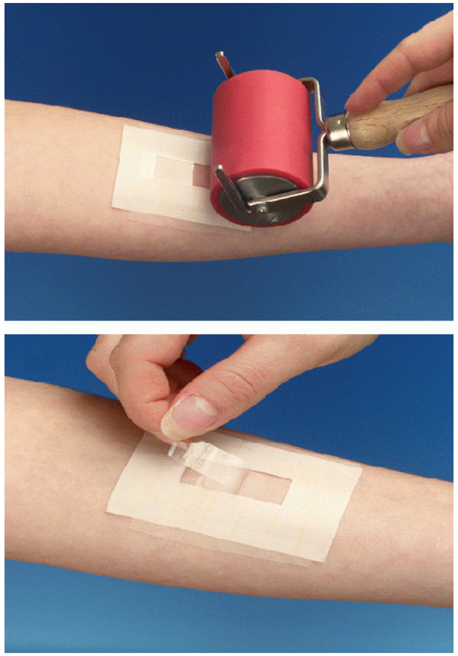
The aim of this work is to develop a method for calculating stratum corneum (SC) properties from measurements of TEWL changes during tape stripping.

Examples where tape stripping is used:-

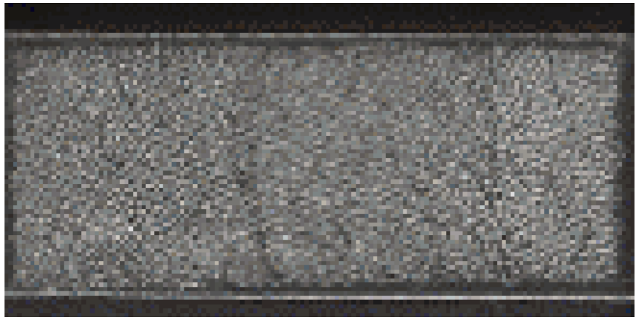
- Measuring the penetration of topical chemicals
- Diagnosing skin health
- Studying skin barrier repair
- Typology

Note: The model can also be adapted to nail stripping, laser ablation, etc.

Tape Stripping



Tape stripping is a minimally invasive technique where adhesive tape is used to remove successive layers of SC, as illustrated on the left. The photo below shows what a tape looks like after a strip.

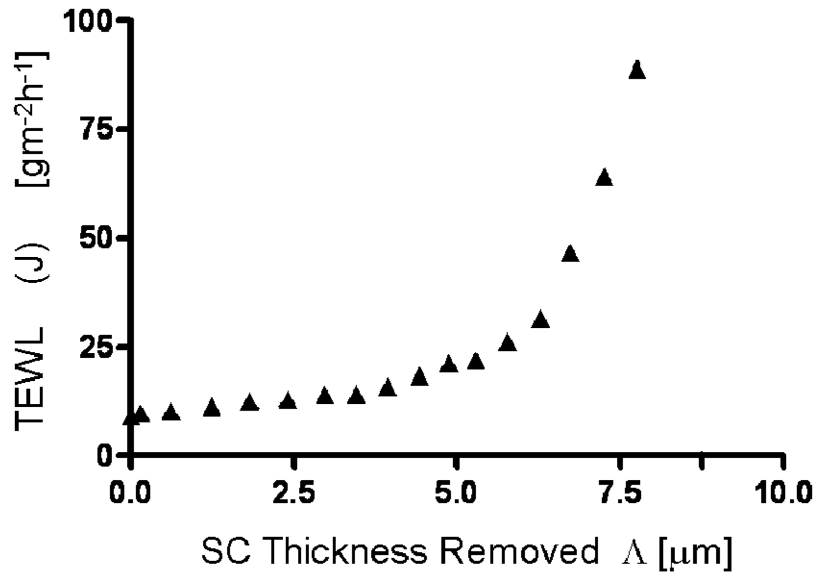


For each strip you can measure:-

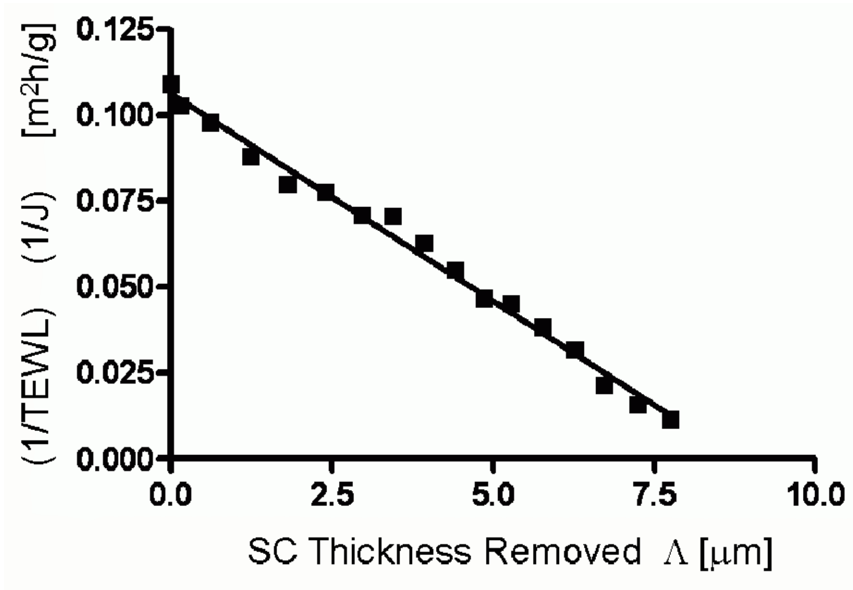
The quantity of SC removed	→	Mean SC thickness removed
The concentration of actives	→	Penetration
Transepidermal water loss (TEWL)	→	Barrier property
Etc.		

TEWL Changes during Stripping

TEWL increases as more SC layers are removed.



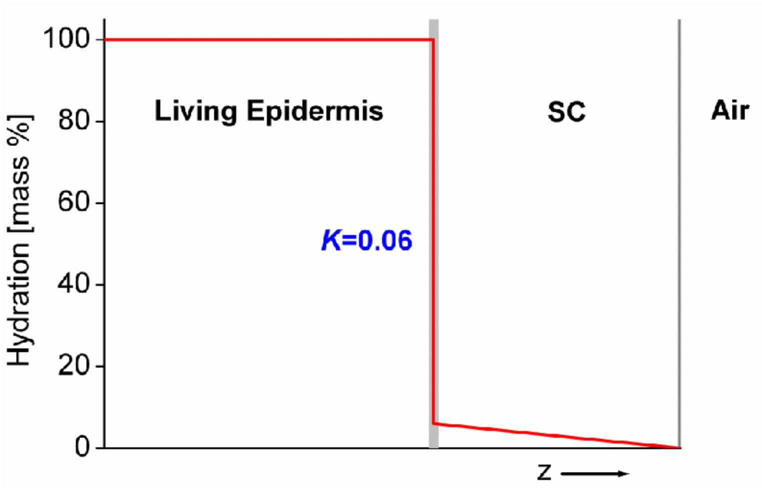
The reciprocal (1/TEWL) is often found to decrease ~linearly with the cumulative thickness of SC removed (Λ) [1].



Figures adapted from [1]

Current Model: Kalia, Pirot & Guy

The model of Kalia, Pirot & Guy [2] used the hydration profile illustrated below, with a water partition coefficient of ***K***=0.06 at the interface between the living epidermis and the base of the SC.



They included the thickness of SC removed (Λ) in Fick's first law, ie

$$J = TEWL = \frac{D \cdot K \cdot \Delta c}{(L - \Lambda)}$$

This analysis gives a linear ***1/J*** plot, with an x-axis intercept equal to the thickness of the intact SC.

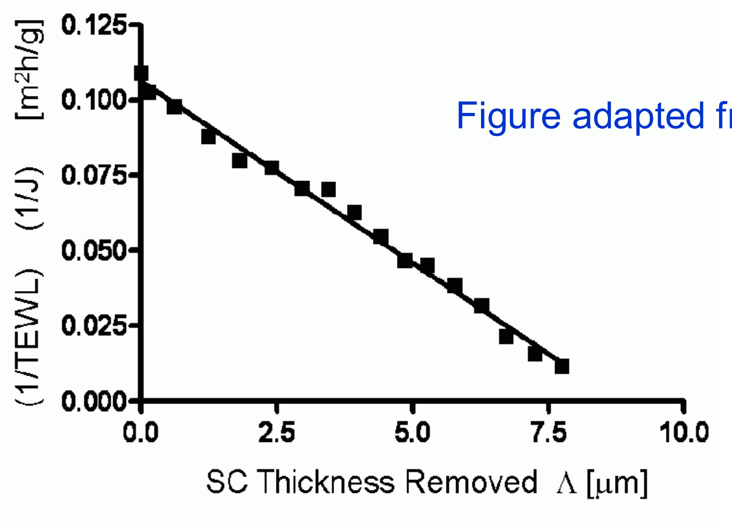
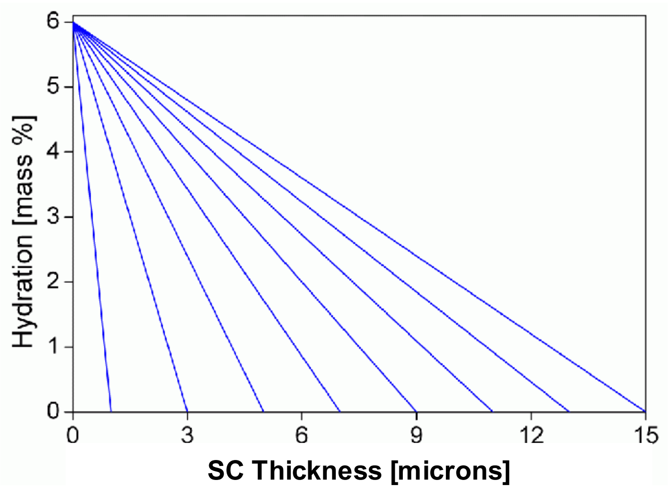


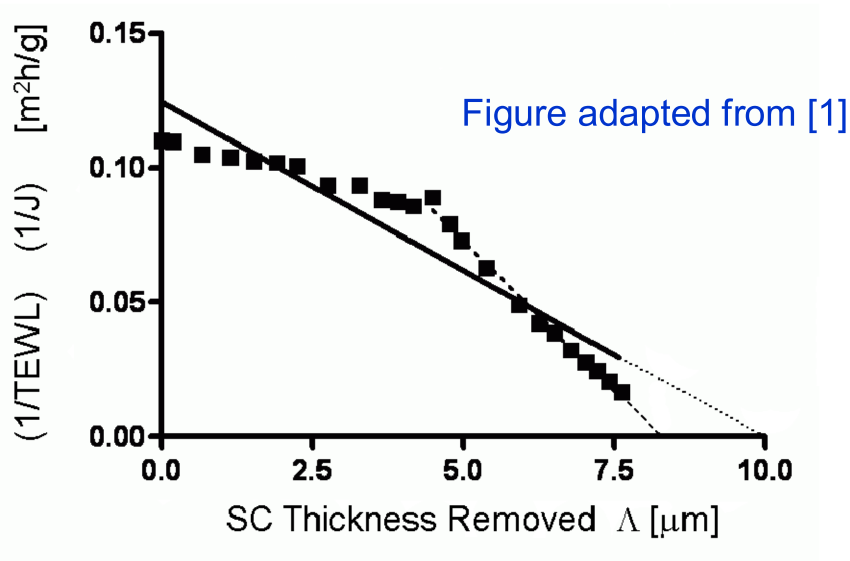
Figure adapted from [1]

Limitations of the Kalia Pirot & Guy Model

1. The assumed SC hydration profiles are unrealistic, because the SC surface remains perfectly dry, as illustrated below.

2. The model does not account for non-linear ***1/J*** plots that are sometimes observed, see below.

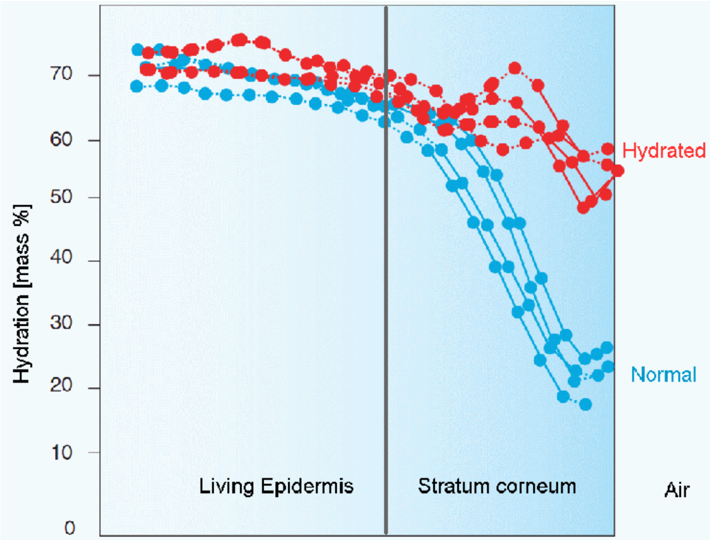




Our proposed new model takes into account (a) a more realistic hydration profile, (b) the interaction between the SC surface and air, and (c) transient effects when the SC surface is disturbed. A uniform SC is assumed here, but the model can be extended to include SC heterogeneity.

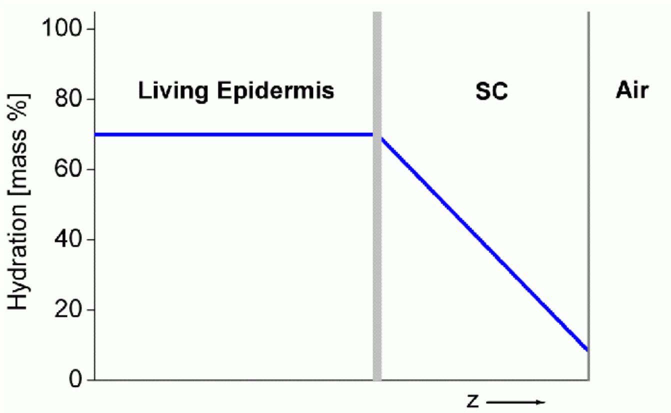
Components of the New Model

Zone 1: Skin



Hydration depth profiles measured using confocal Raman spectroscopy.

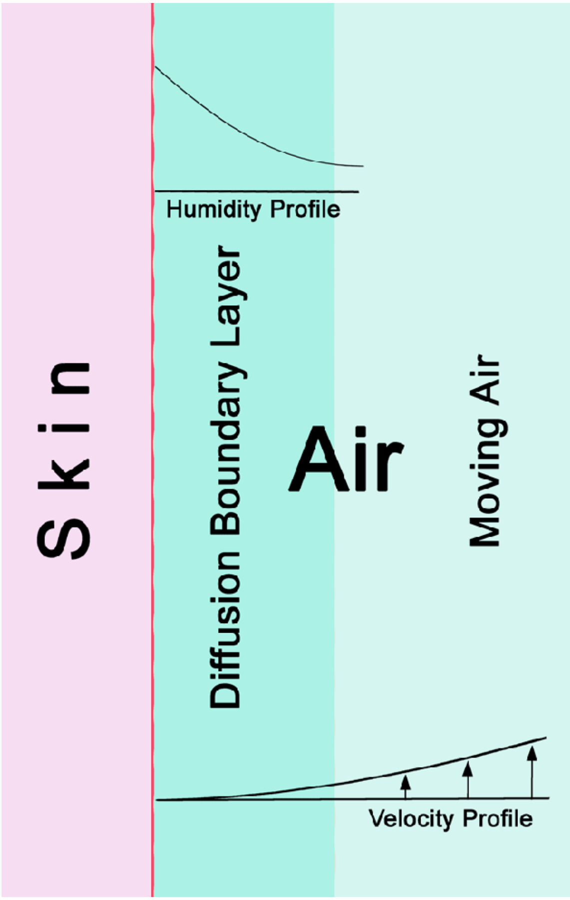
Figure adapted from [3].



Hydration depth profile of the proposed new model, assuming an uniform SC.

Components of the New Model

Zone 2: Air



Water evaporates from the SC surface into the adjacent air. The air immediately next to the SC surface forms a **diffusion boundary layer** of still air [4]. The moving air next to the diffusion boundary layer acts as a **vapour sink** of constant humidity and temperature.

The thickness of the diffusion boundary layer depends on the properties of the moving air [5], eg:-

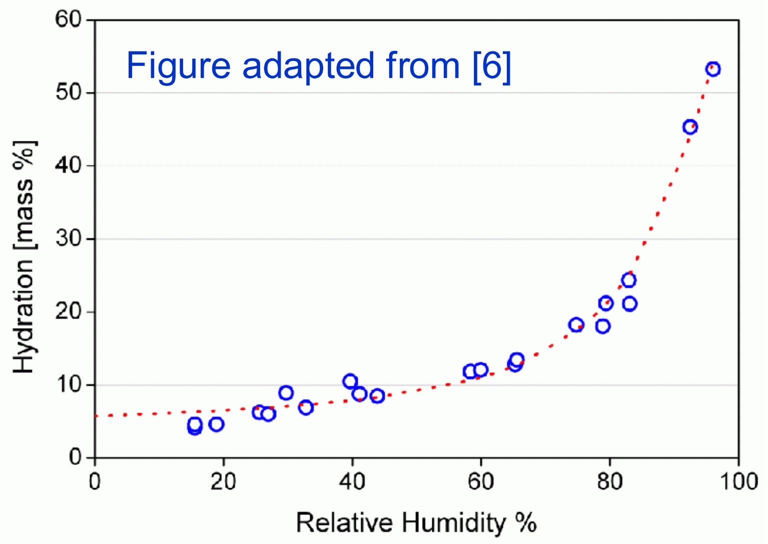
~6mm: Normal room conditions.

~12mm: Very still air.

~24mm: OpenTEWL measurement chamber.

Connection between Skin & Air

The connection between the skin (zone 1) and the adjacent air (zone 2) is the **sorption isotherm**.

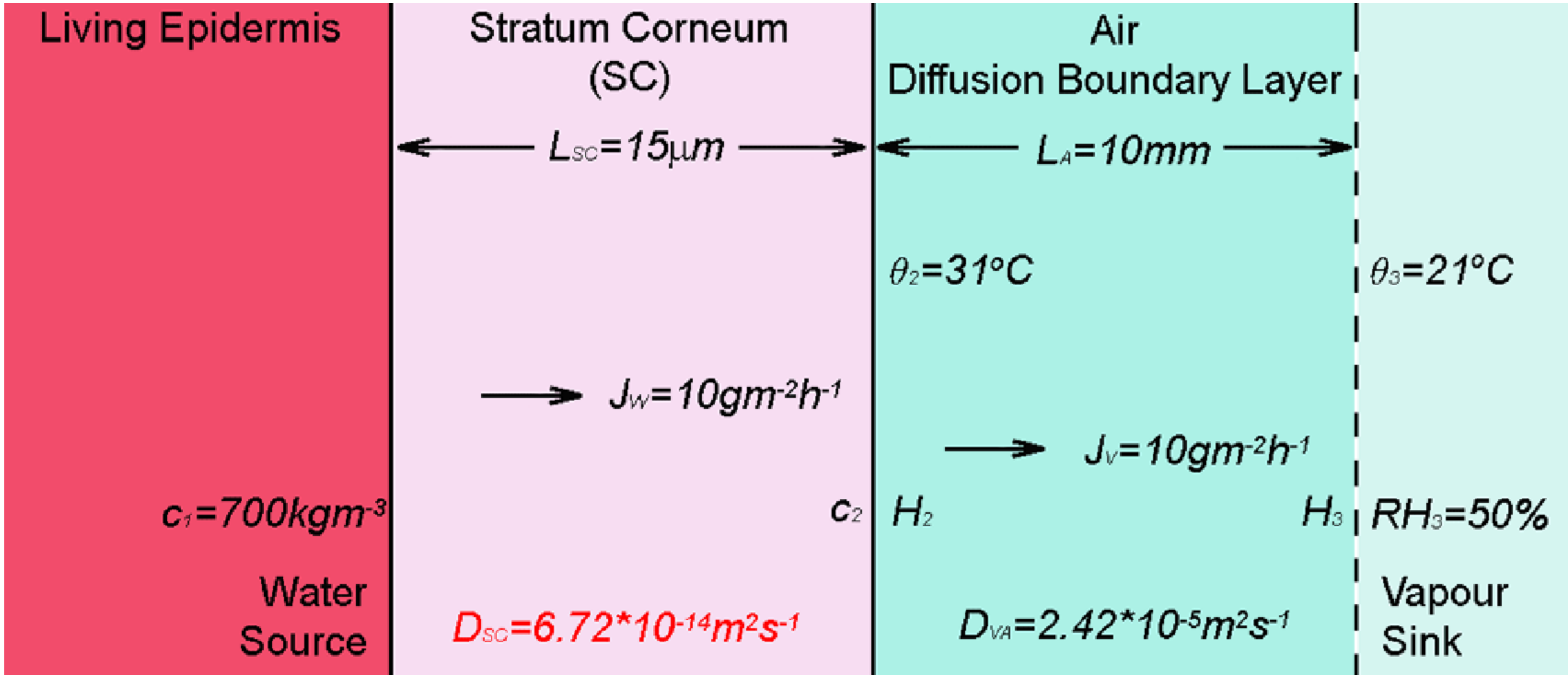


Adsorption & desorption processes at the SC surface maintain a balance between the **hydration** of the SC and the **humidity** of the adjacent air.

The SC surface adapts rapidly to humidity changes, because only the top layer of the SC is exposed to air.

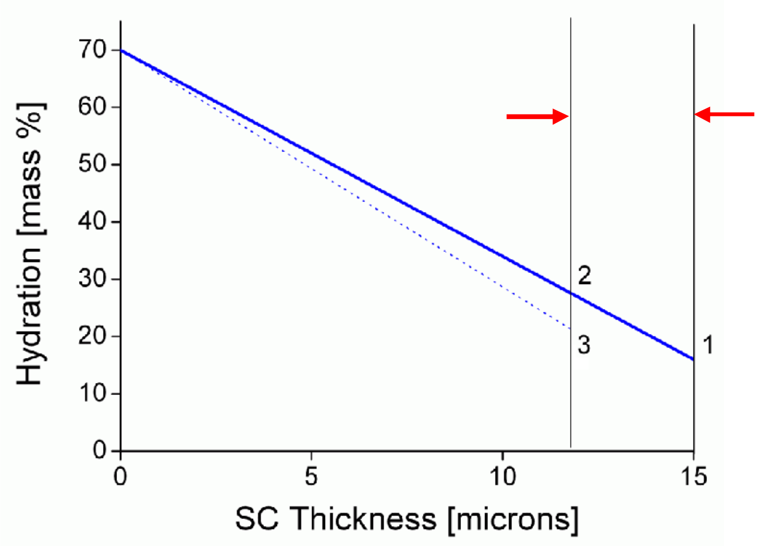
The bulk of the SC takes longer to adapt, because of the low mobility of water in the SC.

Example Calculation with New Model



The parameters in **black** were used in this example calculation. They are sufficient to determine the diffusion coefficient of the SC, D_{SC}, for an assumed TEWL of 10 $gm^{-2}h^{-1}$ for intact SC.

Model of the Stripping Process



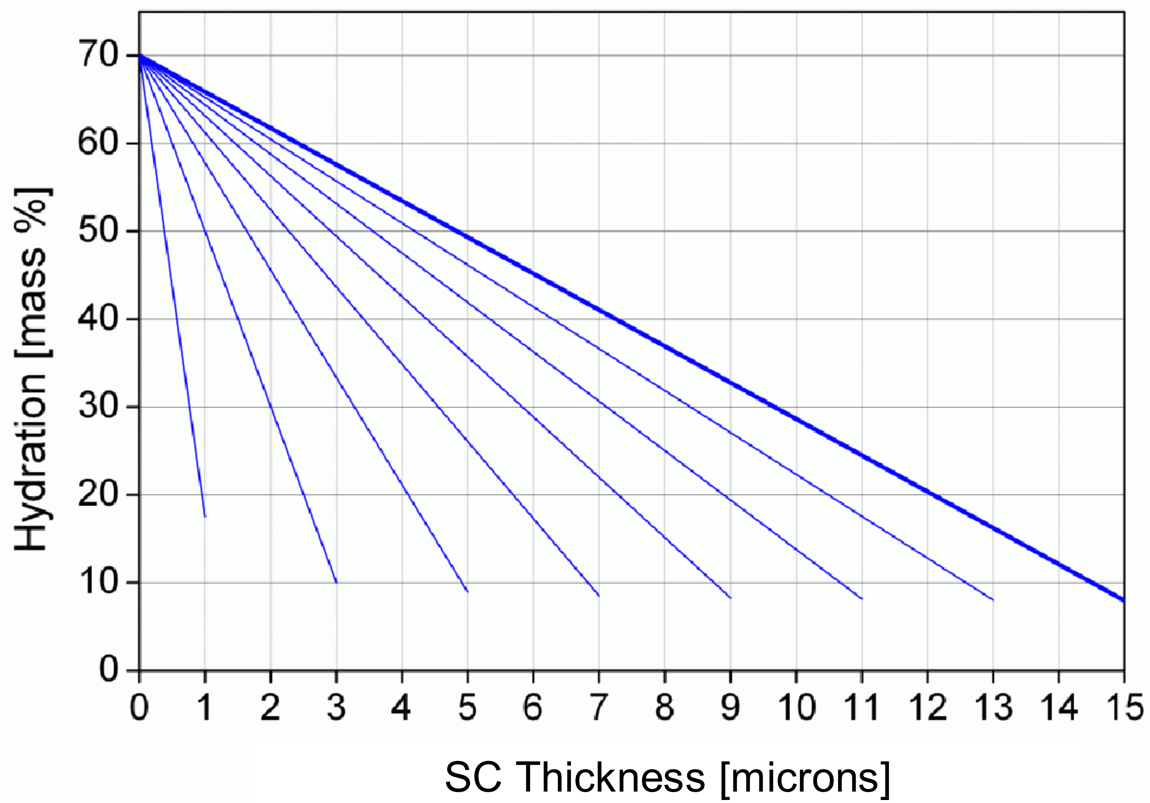
An exaggerated strip thickness of 2μm is assumed here, to illustrate the stripping process more clearly.

Point 1: Before stripping
Steady-state surface hydration, hydration gradient & TEWL.

Point 2: Immediately after stripping
The surface hydration is elevated, therefore the vapour flux has increased.
However, the hydration gradient is unchanged, therefore the TEWL is unchanged.

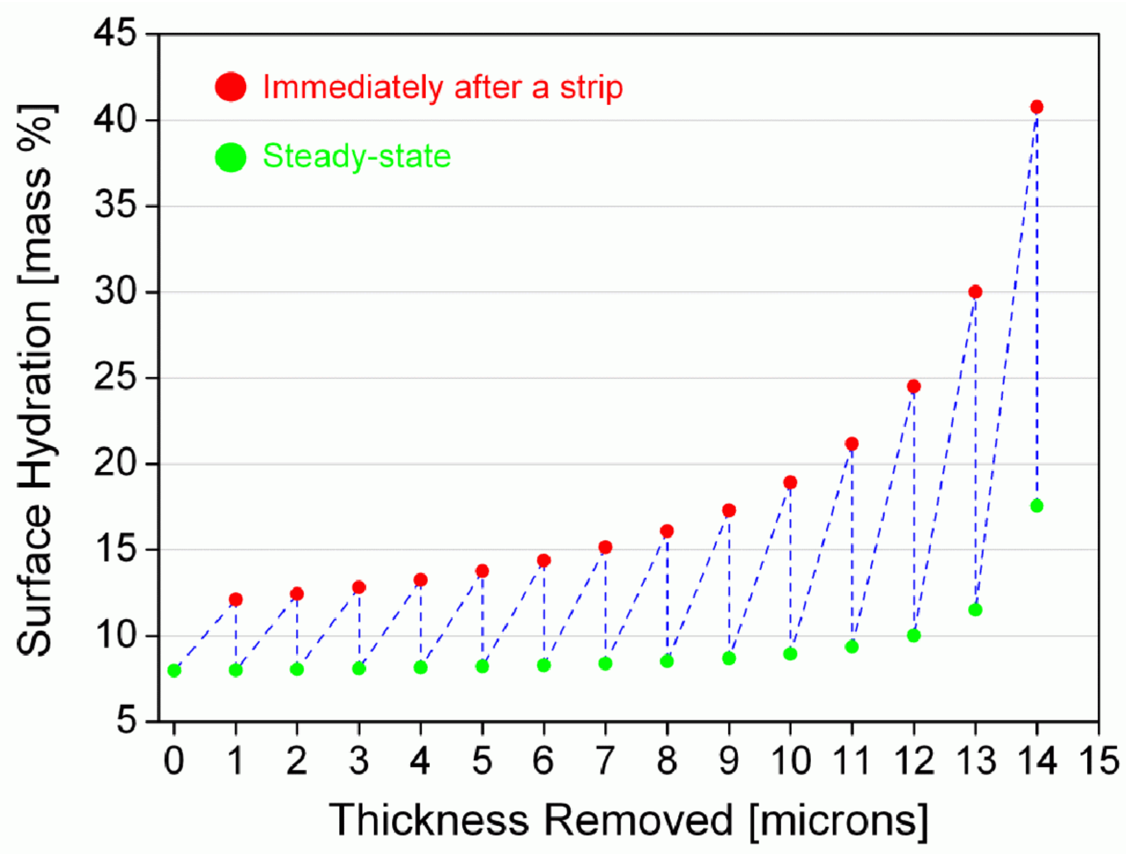
Point 3: After a new steady-state is reached
Surface hydration has decreased to a level above that at Point 1.
The hydration gradient is now more negative than before the strip. TEWL has therefore increased.
Vapour flux and TEWL are now equal.

Steady-state Hydration Profiles



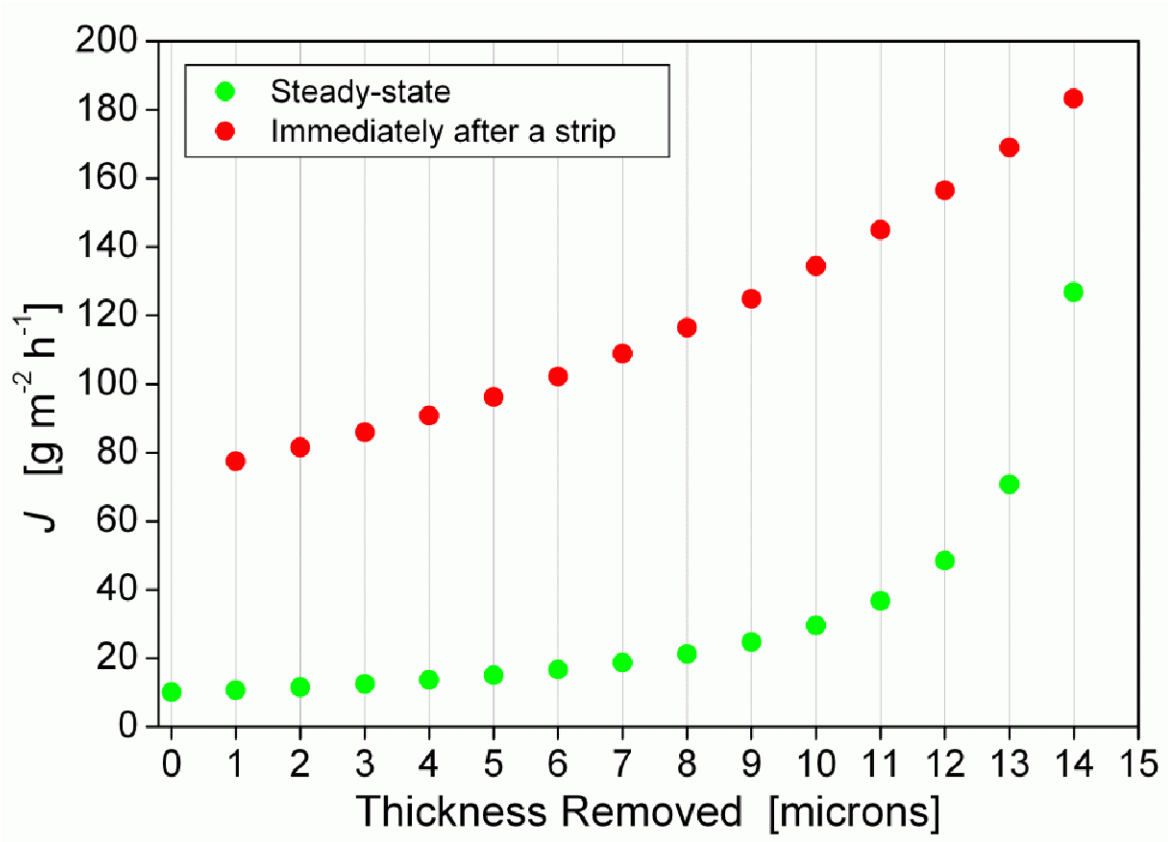
This figure shows calculated steady-state hydration profiles with 0, 2, 4, ... microns of SC removed by stripping. Note the increase of steady-state surface hydration (the end-points of the blue lines) as more layers are stripped.

Transient & Steady-state SC Surface Hydration



This figure shows calculated transient & steady-state SC surface hydration with 0, 1, 2, ... microns of SC removed by stripping. The excess hydration immediately after a strip is subsequently lost by evaporation from the SC surface (=Skin Surface Water Loss, SSWL).

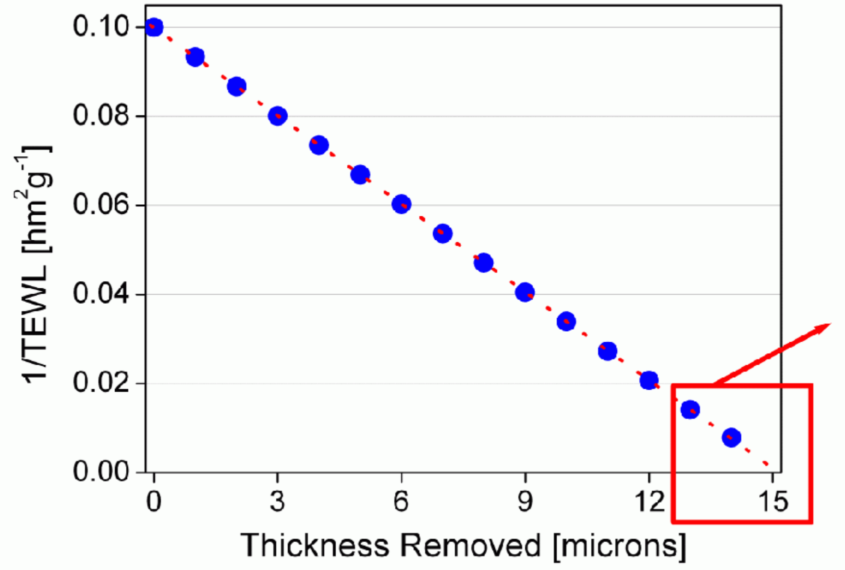
Steady-state & Transient Vapour Flux

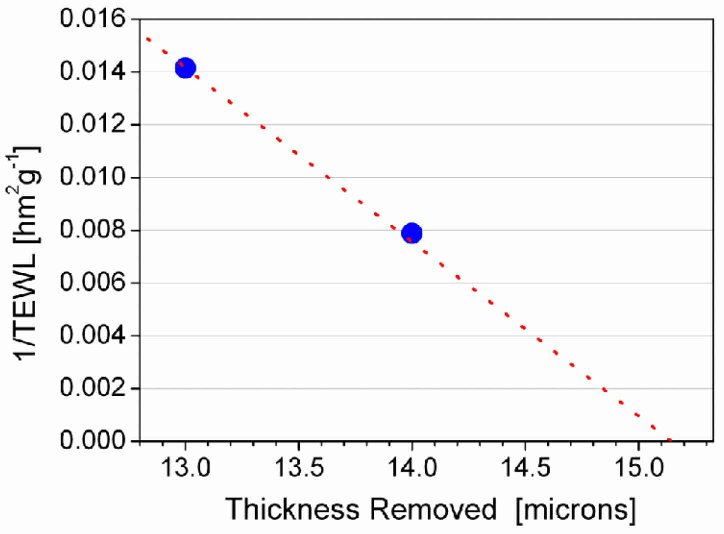


The transient vapour flux is calculated immediately after strips of 1 µm thickness.

This is Skin Surface Water Loss (SSWL)

1/TEWL Dependence





Notes:-

1. The values plotted are steady-state TEWL
2. The intercept gives 1/TEWL = 15.14 µm, for an intact SC thickness of 15.0 µm.
3. The last point deviates slightly from the trend line
4. The agreement with the Kalia, Pirot et Guy model [2] is remarkable

Summary

1. The new model calculates diffusion in two connected zones (SC & adjacent air)
2. The zones are connected through the sorption isotherm
3. Surface sorption/desorption is assumed to be rapid
4. Hydration changes within the SC are more languid

Conclusions

1. The model predicts a nearly linear Λ vs 1/TEWL relationship
2. Sorption isotherm non-linearity has little effect on 1/TEWL curves
3. Observed non-linearity of 1/TEWL curves [1] must therefore be caused by SC heterogeneity
4. The model can be extended to include SC heterogeneity & dynamic effects

References

1. Russell, L and Delgado-Charro, MB: ***Determination of Stratum Corneum Thickness: An Alternative Approach?*** Skin Forum Poster, London (2007).
2. Kalia, YN, Pirot, F and Guy, RH: Homogeneous transport in a heterogeneous membrane: Water diffusion across the human stratum corneum in vivo. Biophysical Journal. 71: 2692-700 (1996).
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6. Lévêque, J-L: ***Water-keratin interactions***. In: Bioengineering of the skin: Water and the stratum corneum. (Elsner, P, Berardesca, E, Maibach, HI, eds), pp. 13-22. CRC Press, Boca Raton (1994).