Mathematical Modelling for Water Concentration Depth Profiles and Water Migration within the Stratum Corneum

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Aim

The aim is improved understanding of the stratum corneum (SC) barrier though modelling of our opto-thermal (OTTER) & TEWL measurements.

Models are based on Miller et al [1] and Wu [2-3].

Ie macroscopic, structureless materials. No bricks. No mortar.

[1] D L Miller, A M Brown and E J Artz, *Indirect measures of transepidermal water loss. Bioengineering and the Skin*, (Editors: R Marks & P A Payne) **19**, 161-71, MTP Press, Lancaster 1979.

[2] M-S Wu, *Water diffusivity and water concentration profile in human stratum corneum from transepidermal water loss measurements*. J Soc Cosmet, **34**, 191-6, 1983.

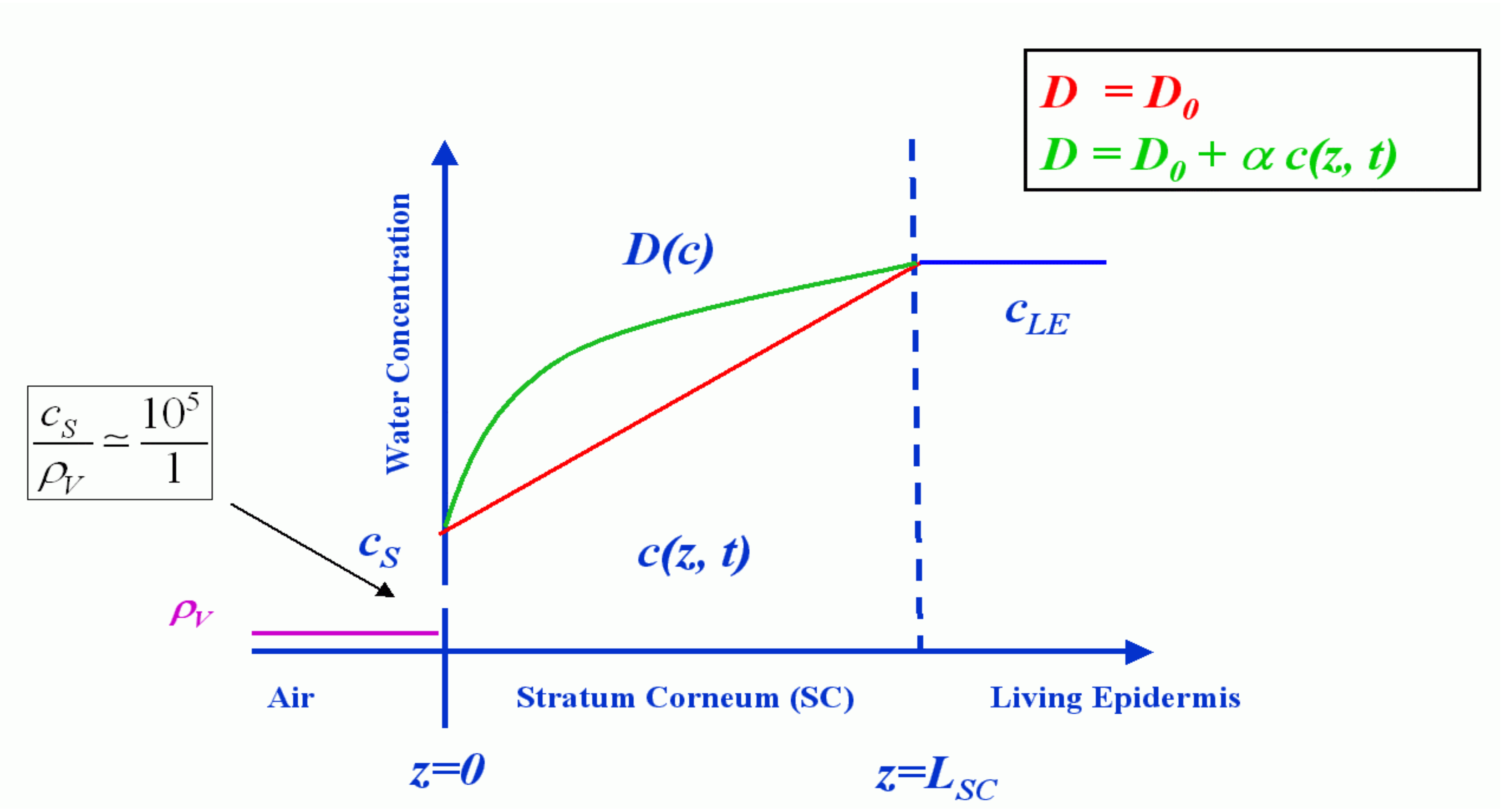
[3] M-S Wu, *Determination of concentration-dependent water diffusivity in a keratinous membrane.*

J Pharmacol Sci, **12**, 1421-3, 1983.

Presentation Outline

1. Steady-state model assumptions
2. SC barrier resistance & TEWL
3. Dynamic modelling
4. Bath dynamics
5. Opto-thermal measurements
6. Conclusions

Steady-state Model Assumptions



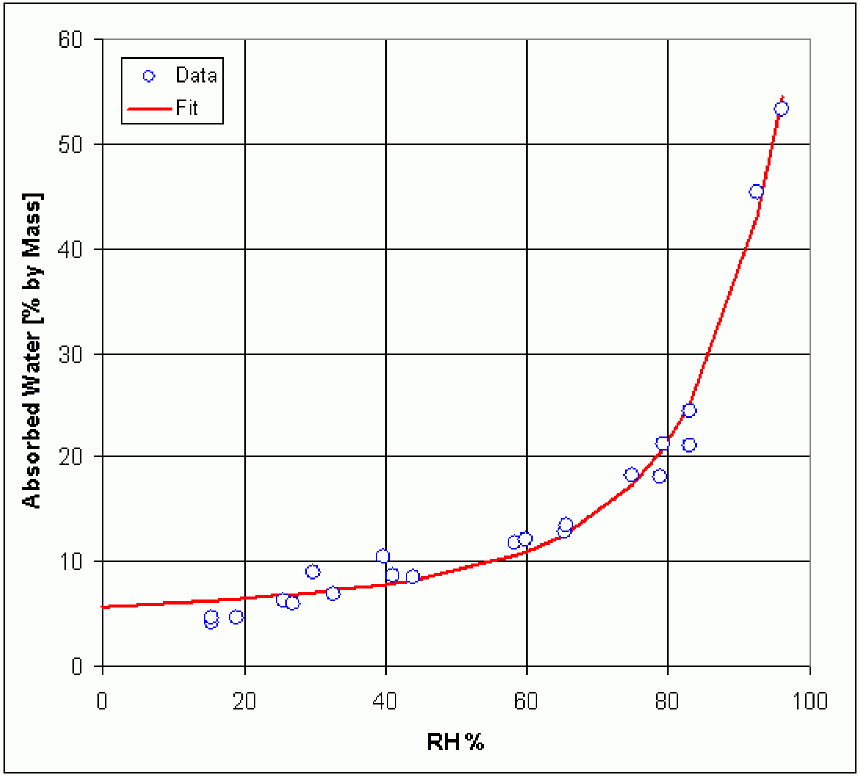
Solution for SC Barrier Resistance & TEWL

Assume:-

1. Steady-state diffusion with constant $\boldsymbol{D_0}$.
2. Use Electrical Analogy [1] with SC barrier resistance $\boldsymbol{R_{SC}=L_{SC}/D_0}$.
3. Flux continuity at the SC surface.
4. Sorption Isotherm relates $\boldsymbol{c_S}$ to surface RH c_S.
5. Vapour flux $\boldsymbol{J}$ measured with a TEWL instrument.

[1] A E Wheldon & J L Monteith, *Performance of a Skin Evaporimeter*, Med Biol Comput, **18**, 201-5, (1980).

Surface Evaporation - Sorption Isotherm



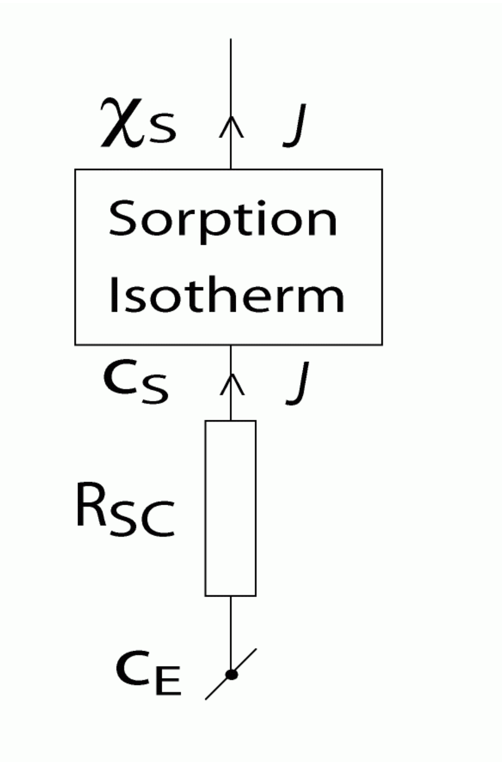
Data from Lévêque [1], digitised from an enlarged photocopy.

[1] J-L Lévêque: *Water-Keratin Interactions.* In *Bioengineering of the Skin: Water and the Stratum Corneum*, (Editors: P Elsner, E Berardesca & HI Maibach), 2, 13-22 CRC Press, Boca Raton 1994.

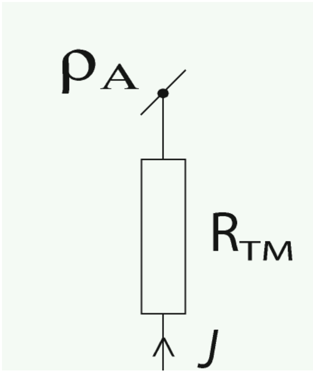
Electrical Analogy

Use electrical analogy of Fick's Law, with **equivalent circuits** for skin & measurement devices.

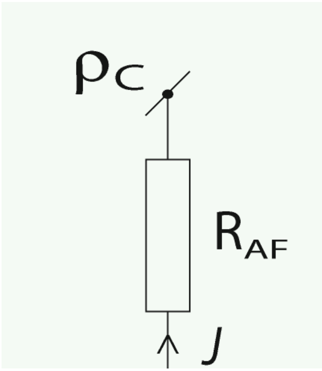
Skin



Open-Chamber

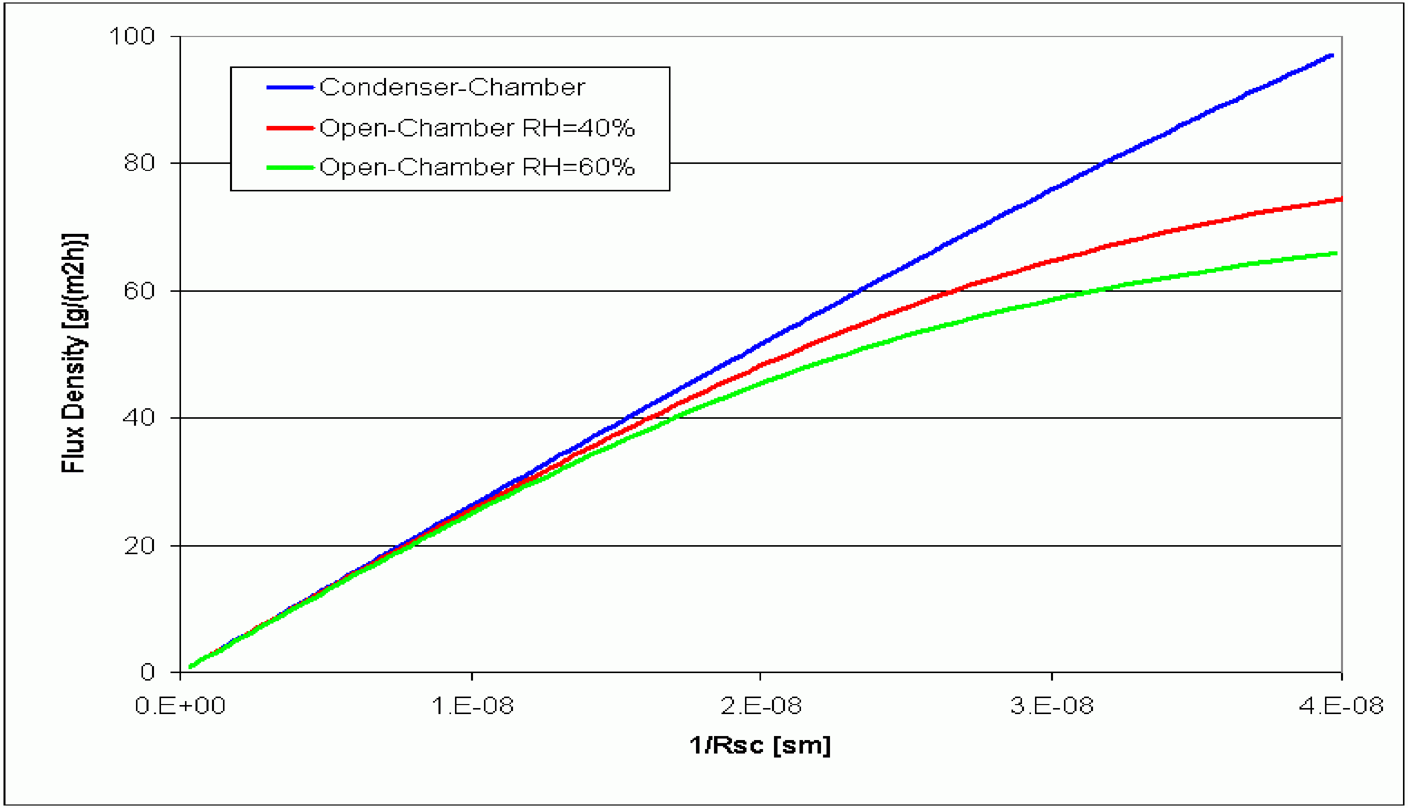


Condenser-Chamber



NB:- R_{SC} is **Stratum Corneum Barrier Resistance**.

Barrier Resistance & TEWL Model Result



Calculated dependence of flux density on ***1/R$_{SC}$*** (SC Conductance).

Barrier Resistance & TEWL Model Conclusions

With a **high** barrier resistance, all techniques measure the same TEWL.

(The barrier controls the water supply & surface RH remains low)

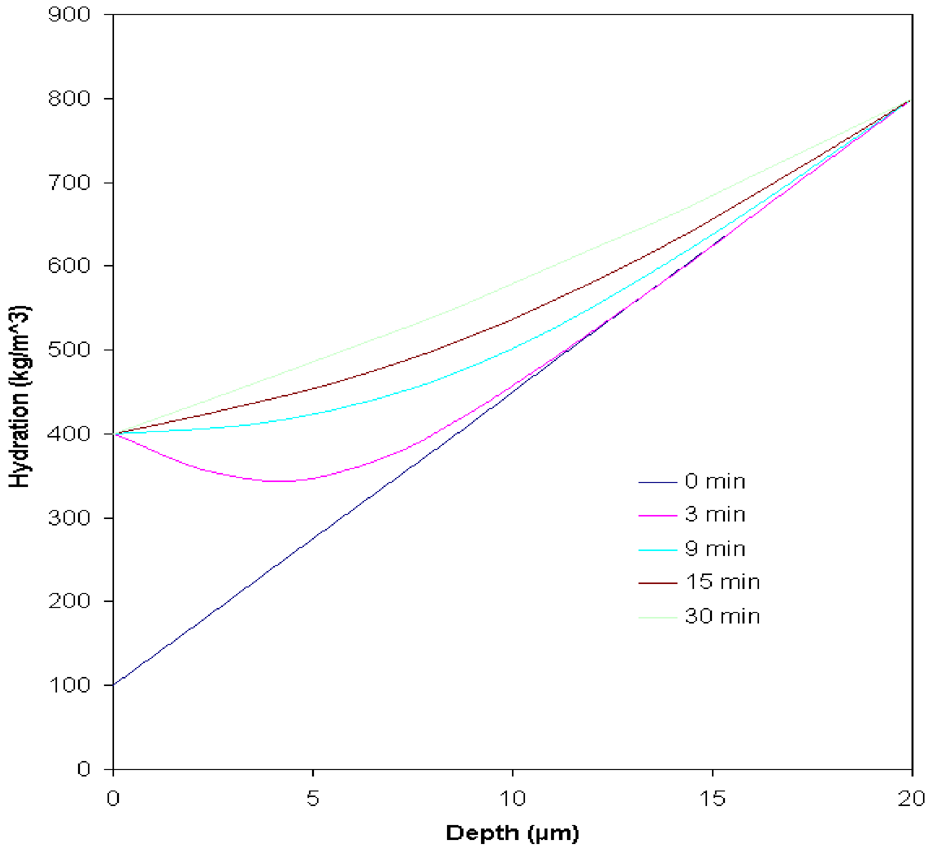
With **lower** barrier resistance, microclimate becomes important.

(because surface RH approaches saturation)

Dynamic Modelling

1. Use Finite Element computation.
2. Study dynamic response to sudden perturbations.
3. Other assumptions as before.

Bath Dynamics 1: Hydration Depth Profile



SC Surface

Living Epidermis

At t < 0:- Steady TEWL

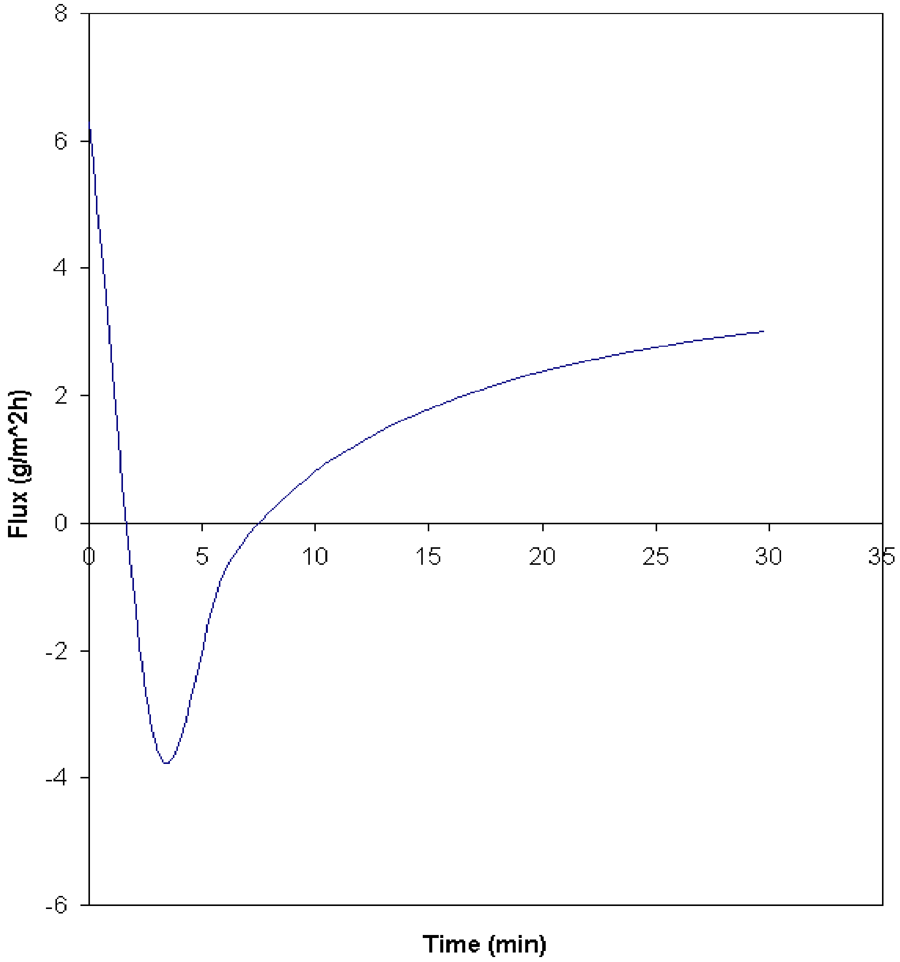
At t = 0:- Get into the bath

(assume 400/1000 partitions into SC surface)

At t > 0:- Hydration profile adjusts.

Note the -ve gradient at ~3 minutes.

Bath Dynamics 2: Surface Flux



At t < 0:- Steady TEWL ~ 6 g m^{-2} h^{-1}

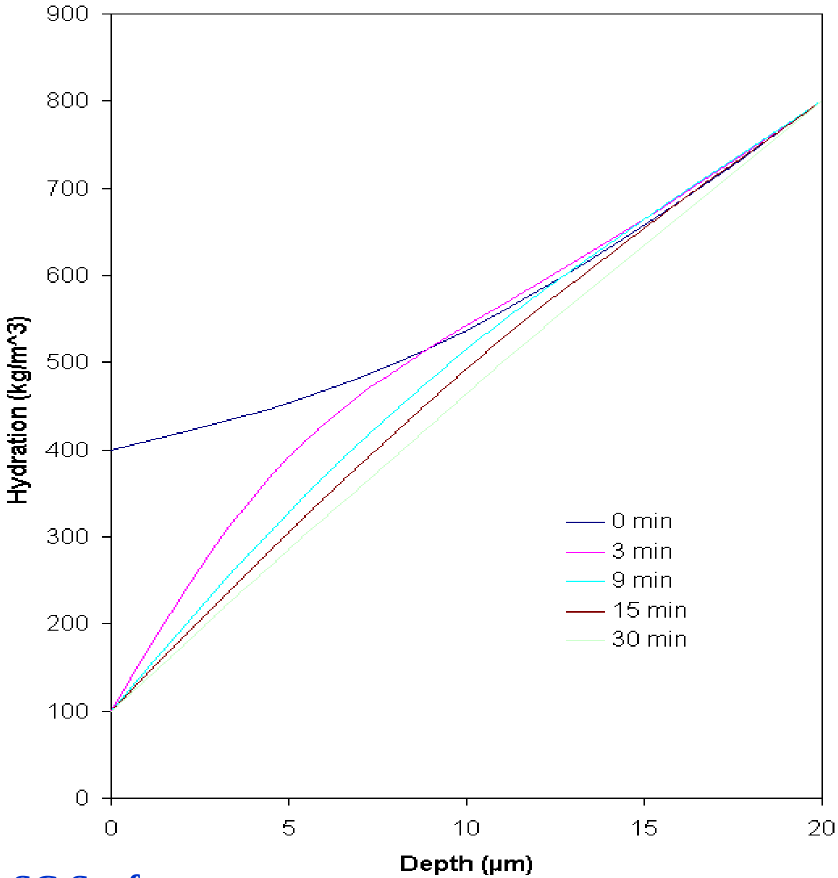
At t < 4 min:- Flux reversal!

(are you drinking through your skin?)

At t > 30 min:- Reduced, steady TEWL

(no, it's coming out again)

Bath Dynamics 3: Drying off



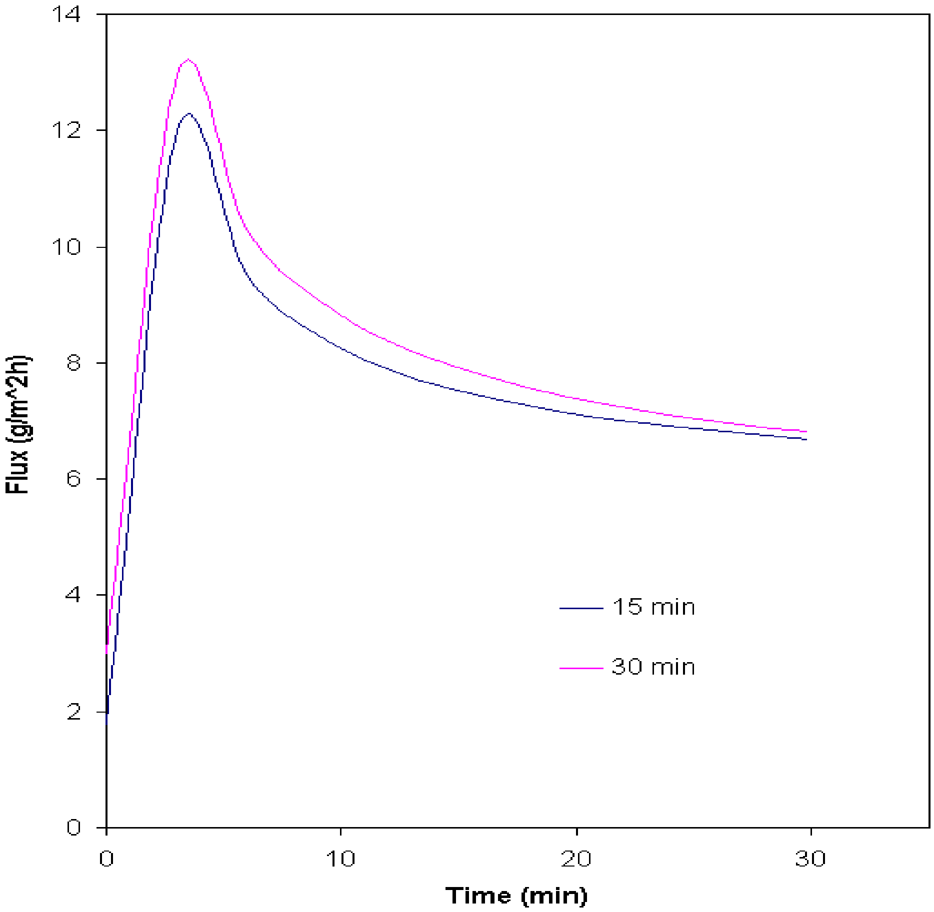
SC Surface

Living Epidermis

Hydration depth profile goes back to normal.

Note that the near-surface gradient goes through a maximum before settling to the new steady-state.

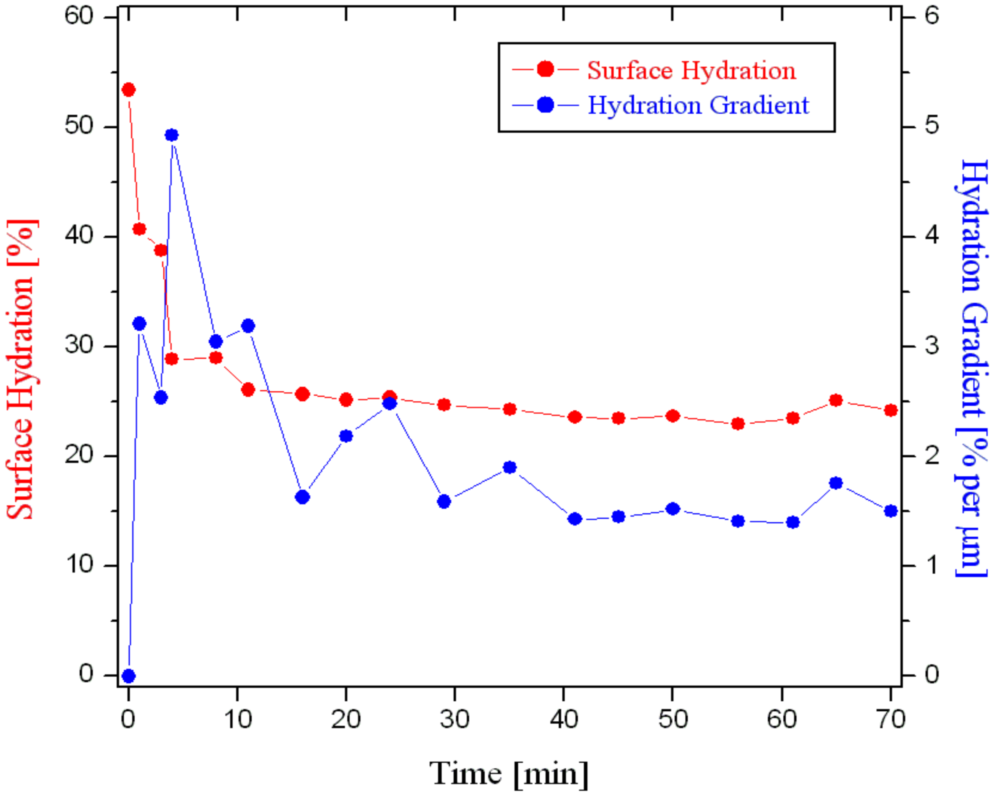
Bath Dynamics 4: TEWL Recovery



These look remarkably similar to Occlusion Recovery Curves.

Clearly, multi-exponentials, even with reconvolution, are off-target!

Opto-thermal Measurements



These are in-vivo hydration recovery measurements on a finger that had been dipped in water for ~ 30 minutes.

Note that the measured hydration gradient goes through a maximum, as predicted by the model.

Conclusions

1. Opto-thermal & TEWL measurements can be used to:-

   Test assumptions & approximations

   Provide parameter values

   Verify predictions

2. Further modelling work is planned:-

   Hydration-dependent diffusion

   SC swelling

   Occlusion dynamics

   SC Stripping

   etc.