# Hair Water Content and Water Holding Capacity Measurements


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## Introductions

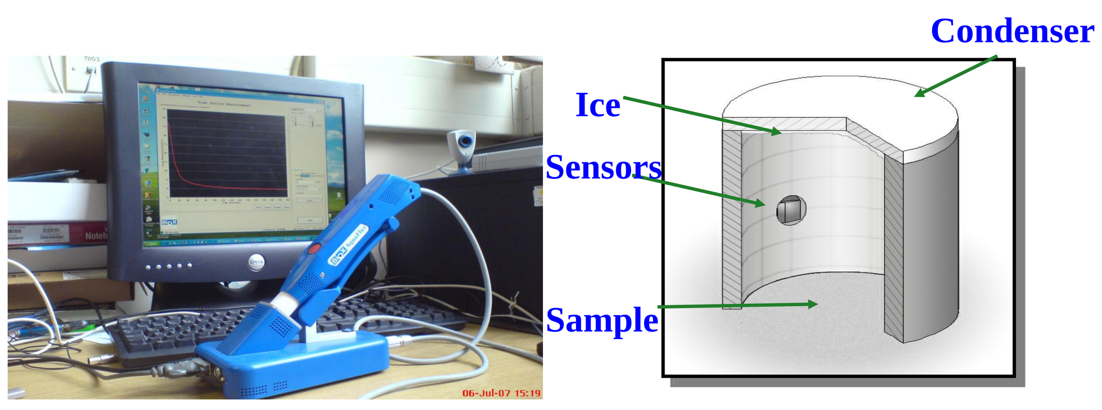
Human hair is a skin appendage which has huge cosmetic importance. In this paper, we present our latest study on human hair water content and water holding capacity measurements by using capacitive contact imaging and condenser-TEWL method. Previous studies showed that capacitive contact imaging based fingerprint sensors, originally designed for biometric applications, can be used for skin hydration imaging, skin surface analysis, 3D skin surface profiles, skin micro-relief as well as solvent penetration measurements [1,2]. Through calibration, we can measure the absolute dielectric constant [3], from which we can calculate the absolute water content of the samples. In this study, we used capacitive contact imaging for hair water content measurements, and compared it with other measurement techniques. The results show that capacitive contact imaging can effectively differentiate different hairs from different people, normal hair from wet hair, and water content changes in hair.

Healthy hair always contains certain amount of water, and will contain different amount of water when exposed to different relatively humidity (RH) environments. We studied this water holding capacity by using the condenser-TEWL method [4] through desorption process, in which small hair samples were placed inside the measurement chamber (22ºC and 11.3% RH). These hair samples, pre-conditioned at different higher RH, will therefore lose water until they reach equilibrium with the chamber RH. The dynamics of the equilibration process can be studied by measuring time-series curves of associated water vapour flux. The total quantity of water lost can then be calculated from such time-integrated flux curves. We have also developed mathematical models for modelling this hair desorption process. By fitting the normalized hair desorption data with the mathematical models, we can get the water diffusion coefficient information, which can then be related to the water holding capacity of the hair samples.

## Apparatus

The Epsilon Permittivity Imaging System is based on Fujistu fingerprint sensor (Fujistu Ltd), which has 256x300 pixels with 50µm spatial resolution. Each pixel is equivalent to a capacitive sensor, which measures the dielectric constant or permittivity of the sample. It has a 8-bit grey-scale capacitance resolution per pixel (0 - 255). See **Figure 1 (A, B, C)**. AquaFlux is a novel close-chamber TEWL method, the cylindrical measurement chamber is open at one end which is in contact with skin surface, and it is closed at another end with a cold plate - condenser. The closed chamber with a condenser helps to stabilize the measurement environment and therefore enhance repeatability and accuracy of the measurement results. See **Figure 1 (D, E)**.

**A) Epsilon with in-vitro stand** **B) Epsilon with in-vivo stand** **C) Measurement Principle [5]**




**D ) AquaFlux** **E) Measurement Chamber**

**Figure 1.** Epsilon and AquaFlux.

## Materials and Methods

For hair water content measurements using Epsilon, if we assume that the dielectric constants of the hair samples are linearly dependent on the dielectric constants of dry samples and water, then we can work out the hair samples' water content using the measured dielectric constants, [6],

$$H = \frac{\varepsilon_m - \varepsilon_{dry}}{\varepsilon_{water} - \varepsilon_{dry}} \times 100 \qquad (1)$$

where $\varepsilon_m$ is the measured dielectric constant, $\varepsilon_{dry}$ is the dielectric constant of the dry hair samples, and $\varepsilon_{water}$ is the dielectric constant of water, H is sample's water content in volume ratio percentage. In this paper, we will use Eq.(1) for calculating the water content in hair with values of $\varepsilon_{water} = 80$, and $\varepsilon_{dry} = 1$.

For hair desorption measurements using AquaFlux, a small amount of hair samples, collected from different healthy volunteers, were placed in a measurement cup which was then coupled to the measurement chamber of the condenser-TEWL method. The hair samples will gradually loose their water content through natural evaporation. The water vapour that comes from the hair samples will go into the measurement chamber, passing through the relative humidity and temperature sensor, and eventually frozen to ice on condenser surface. The water vapour flux density was then recorded for a period of time by the condenser-TEWL method. Through these time series flux density curves we can work out the water holding capacity of the samples. The normalized hair desorption curve can be expressed as [7]

$$J = \frac{\sum_n \frac{1}{\beta_{n0}} e^{-(\frac{D}{R^2})\beta_{n0}^2 t}}{\sum_n \frac{1}{\beta_{n0}}} \qquad (2)$$

By fitting the desorption experiment data with Eq.(2), we can have the best fit $\frac{D}{R^2}$ values, which reflect a standardized diffusion coefficient. The higher the value the faster the hair losing its water, and hence the poorer water holding capability.

## Results and Discussions

Figure 2 shows the capacitive images of in-vivo hair samples from five different volunteers, and the corresponding average dielectric constants and the standard deviations of the images. The water content calculated using Eq.(1) is expressed as volume ratio percentage.

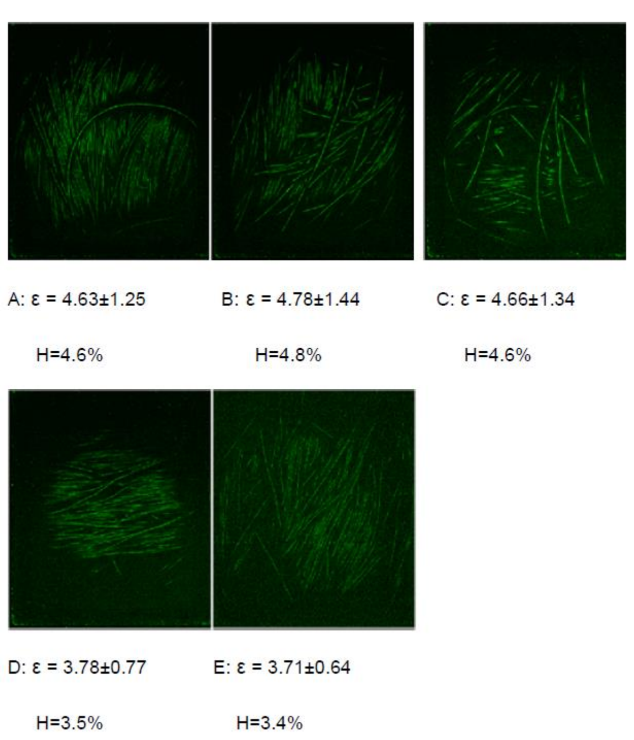
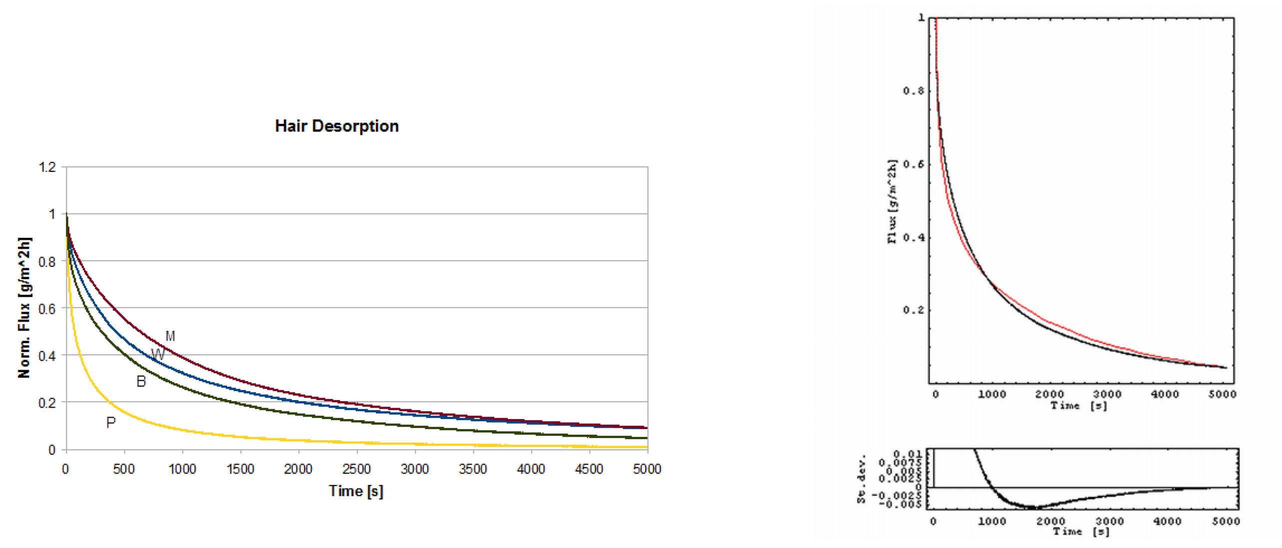



**Figure 2.** The capacitive Images of different hairs from four different volunteers, A (male, >60 yrs, grey colour, Caucasian), B (female, 40-50 yrs, brown colour, Caucasian), C ( male, 20-30 yrs, brown colour, Caucasian), D ( female, ~20 yrs, black colour, Asian), E ( female, ~11yrs, black colour, Asian).

The results show that there is no systematic trends of water content changes in hair of different ages, different genders, and different races. However, the smaller dielectric constant standard deviations in the hair of younger volunteers might suggest that the water distributions in hair are more uniform than that of elder volunteers.

In hair desorption measurements, hair samples, freshly cut from 4 healthy volunteers (W, P, M, B) including both male and female adults and a child, were used. Each hair sample was bundled with a foil, and then placed in a measurement cup, placed on condenser-TEWL method probe, which measure the water vapour loss from hair continuously for a period of 4000 seconds. The hair will naturally loose his water content through drying process, e.g. desorption.

The raw hair desorption flux density curves depend on the quantity of hair, total surface area exposed etc, normalize the flux density curves to its peak value can maximally eliminate these factors. **Figure 3 (A)** shows the normalized hair desorption result of volunteers, noted as W, P, M and B measured by condenser – TEWL methods. Volunteers P and B are male adults, volunteer W is female adult, and volunteer M is female child. The volunteer M has the slowly desorption rate, whilst the male adult volunteer P has the fastest desorption rate. **Figure 3 (B)** show a typical least squares fitting curves between the theoretical data (Eq.(2)) and experimental data, the results show that the theoretical data agrees well with the experimental data.




**(A)** **(B)**

**Figure 3.** (A) Hair desorption data of four different volunteers: W (female), P (male), M (child), B(male). (B) A typical Least Squares Fitting curves between theoretical data (Eq. (2)) and experimental data.

**Table 1** shows the best fit $\frac{D}{R^2}$ values of 4 different hair samples. $\frac{D}{R^2}$ value represents the water holding capability of hair. The higher the value the faster the hair loosing its water, and the lower the value the slower the hair loosing its water.

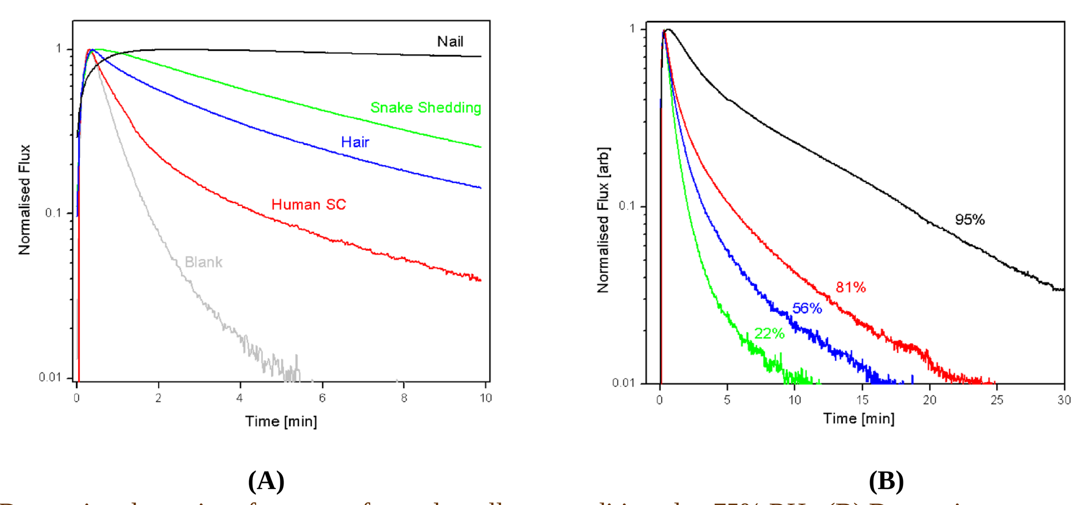
**Table 1.** The best fit $\frac{D}{R^2}$ values of different hair samples

| Volunteers | W | P | M | B |
|---|---|---|---|---|
| $\frac{D}{R^2}$ [$s^{-1}$] | $5x10^{-5}$ | $25x10^{-5}$ | $4x10^{-5}$ | $8x10^{-5}$ |

If we assume that the radius of hair R is in the order of $10^{-4}$ m, then the water diffusion coefficient of hair is in the order of $10^{-13}$ $m^2/s$, which is comparable with that of skin $10^{-13}$ ~ $10^{-14}$ m2/s [5]. This calculated water diffusion coefficient of hair is also very similar to that of wool, which increases as water concentration increases or temperature increases. Cassie's absorption of water by wool study showed there is also an absorption-desorption hysteresis of wool [8]. This feature probably also exists for human hair, and would be interesting topics for future studies.

The different water diffusion coefficient from different hair samples is likely to reflect the different hair's natural water holding capabilities, as these hair samples are untreated and unprocessed. The results show that the children volunteer M has the lowest water diffusion coefficient, and therefore the best water holding capability, whilst the male adult volunteer P has the highest water diffusion coefficient, which means the worst water holding capability. The water holding capability is likely an index for hair quality, which means volunteer M has the best quality of hair, and volunteer P has the worse quality of hair. It would be interesting to study the effects of hair dressing processes (e.g. bleaching, waving, conditioning etc.) on hair's water holding capabilities in the future studies.

**Figure 4 (A)** shows examples of desorption curves for a range of samples, all preconditioned at 75% RH and measured at an ambient temperature of 22ºC. A normalised, logarithmic flux scale is used to highlight the dynamics rather than the quantity of water desorbed. The blank curve was measured with an empty desorption cap, to indicate the instrumental response time. The desorption curve for excised human SC shows two distinct decay rates that may be associated with different water binding states. The curves for nail and snake shedding have rounded peaks that indicate the establishment of water diffusion and associated concentration gradients within these materials. Nail has the slowest desorption rate, where 51 minutes are required in this case for the desorption flux to decay to half its peak value. **Figure 4 (B)** shows examples desorption curves for excised human SC(stratum corneum) samples pre-conditioned at a range of RH values [9].




**(A)** **(B)**

**Figure 4.** (A) Desorption dynamics of a range of samples, all pre-conditioned at 75% RH . (B) Desorption curves of SC at different RH.

## Conclusions

Capacitive contact imaging shows good potential for in-vivo hair measurements. From measured dielectric constants we can work out the water content in hair. The results show that there is no significant difference in water content of young hairs and old hairs. But the water distribution in young hairs is more uniform. Desorption measurements with a condenser-chamber TEWL instrument give useful results quickly and economically. The results show that different hairs have quite different desorption processes which are likely indicating different water holding capabilities. By fitting the desorption curves with suitable mathematical models we can also extract the water diffusion coefficients of hair. The results show that the diffusion coefficient of hair is very similar to that of skin and wool.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