Hair Water Content and Water Holding Capacity Measurements

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Introduction

Human hair is a skin appendage which has huge economic 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-TWL 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 moisturized as well as volatiles presentation measurements [1,2]. Through calibration, we can measure the absolute dielectric constant [3], from which we can calculate the absolute water content of the sample. In this study, we use 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 thin hair and bone content changes in hair.

Healthy hair always contains a certain amount of water, and will contain different amounts of water when exposed to different relatively humid (RH) environments. We studied the hair water holding capacity by using the condenser-TWL method [4] through desorption process, in which small hair samples were placed inside the measurement chamber (23±1 °C and 55±1 RH). These hair samples, pre-conditioned as different higher RH, will therefore lose water until they reach equilibrium with the chamber RH. The dynamics of the evaporation process can be studied by measuring time-series curves of associated water vapor flux. The water quantity of water loss can be calculated from such time-integrated flux curves. We have also developed mathematical models for modeling the hair desorption process. By fitting the normalised hair desorption data with the mathematical models, we can get the water diffusion coefficient information, which can be related to the water holding capacity of the hair samples.

Materials and Methods

For hair water content measurements using EpiSkin, 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 use the following formula to calculate the hair samples’ water content using the measured dielectric constants [5]:

\[
\varepsilon_{\text{water}} \times \varepsilon_{\text{water}} + (1 - \varepsilon_{\text{water}}) \times \varepsilon_{\text{hair}} = 1
\]

where \(\varepsilon_{\text{water}}\) is the measured dielectric constant, \(\varepsilon_{\text{water}}\) is the dielectric constant of the dry samples, and \(\varepsilon_{\text{hair}}\) is the dielectric constant of water. It is a sample's water content in volume ratio percentage in this paper, we will use Eq(1) to calculate the water content in hair with volume ratio of \(\varepsilon_{\text{water}} \times \varepsilon_{\text{water}} = 8.98 \times 10^{-10}\) at 25°C.

Results and Discussions

Four different hair samples, A, B, C, and D, were used to determine the hair water content and water holding capacity. They are divided into four different groups: Caucasian, Asian, wool, and striped. The results show that there is no systematic trends of water content changes in hair of different ages, different genders, and different times. However, the similar dielectric constant standard deviations in the hair of younger volunteers might suggest that the water distributions in hair are more uniform than that of older volunteers.

Hair desorption measurements, hair samples, freshly cut from four healthy volunteers (W, F, M, M) including both male and female adults and child, were used. Each hair sample was washed with water and then placed in a measurement cup, placed on condenser-TWL method probe, which measures the water vapour loss from the hair for a period of 4000 seconds. The hair will naturally lose the water through desorption process, e.g., desorption.

The new hair desorption flux density curves depend on the quantity of hair, total surface area exposed on, normalised the flux densities to its peak value can maximally eliminate these factors. Figure 3(a) shows the normalized hair desorption rate of volunteers, noted as W, F, M, and B measured by condenser-TWL method. Volunteers P & R are both male adults, volunteer W is female adult; and volunteer M is female child. The volunteer M has the slowest desorption rate, while the male adult volunteer has the fastest desorption rate. Figure 3(b) shows a typical logarithmic fitting curves between the theoretical data (Eq(2)) and experimental data, the results show that the theoretical data agrees well with the experimental data.

Table 1 shows the best fit V values of different hair samples. A, B, C, and D represent the hair holding capability of hair. The higher the value of the hair lossing its water, and the lower the value shows the hair lossing its water.

Figure 3 (A) Hair desorption data of four different volunteer: W (female), P (male), M (child), B (male). (B) A Typical Logarithmic Fitting curves between theoretical data (Eq (2)) and experimental data.

Table 1. The best fit V values of different hair samples

If we assume that the radius of hair R is in the order of 50 μm, then the water diffusion coefficient of hair is in the order of 10^-10 cm²/s, which is comparable with that of hair 10^-10 cm²/s [3]. This calculated water diffusion coefficient of hair is also very similar to that of wool, which increases as water content increases or temperature increases. Castor’s absorption of water by wool model showed that there is also an absorption-desorption hysteresis of wool [3]. This feature probably also exists for human hair, and would be interesting topic for future studies.

The different water diffusion coefficients from different hair samples is likely to reflect the different hair’s natural water holding capacities, as these hair samples are unraveled and supressed. The results show that the children’s hair has the highest water diffusion coefficient, and therefore the hair water holding capacity, while the male adult volunteer has the highest water diffusion coefficient, which means the wool water holding capacity. The water holding capability is likely in index for hair quality, which means volunteer M has the best quality of hair, and volunteer P has the worst quality of hair. It would be interesting to study the effects of hair dressing processes (e.g. brushing, washing, conditioning etc.) on hair’s water holding capacities in the future studies.

Figure 4 (A) shows examples of desorption curves for a range of samples, all pre-conditioned at 75% RH and measured at an experimental temperature of 25°C. A normalised logarithmic flux scale is used to highlight the dynamics rather than the quantity of water desorbed. The black curve was measured with an empty desorption cup to indicate the instrumental response time. The desorptions for the different human SCs show two distinct decay rates that are associated with different evaporation rates. The curves for red and black shading have instead peaks that indicate the establishment of water diffusion and associated concentration gradients within the material. Not all the decayed desorption rates, where the samples are excised in this case for the desorption flux to decay to its peak value. Figure 4 (B) shows examples curves for excised human SCs/tissue samples pre-conditioned at a range of RH.

Table 2. 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 hair and old hair that can be attributed to desorption in young hair to measure water holding capacity of hair. By fitting the desorption with mathematical models, one can also extract the water diffusion coefficients of hair. The results show that the diffusion coefficient is hair is very similar to that of skin and wool.

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References