TRANSEPIDERMAL WATER LOSS (TEWL) MEASUREMENTS WITH TWO NOVEL SENSORS BASED ON DIFFERENT SENSING PRINCIPLES

M. Mündlein[1], B. Valentin[1], R. Chabicovsky[1,*], J. Nicolics[1], J. Weremczuk[2], G. Tarapata[2], R. Jachowicz[2]

[1]Vienna University of Technology, Institute of Sensor and Actuator Systems, A-1040 Vienna, Austria
[2]Warsaw University of Technology, Institute of Electronic Systems, 00-665 Warsaw, Poland

*Corresponding author: Rupert Chabicovsky, Phone +43-1-58801-36651, Fax +43-1-58801-36699, e-mail rupert.chabicovsky@tuwien.ac.at

Abstract: In this paper we compare results of TEWL measurements carried out with two different instruments recently developed in our institutes. One sensor is based on a dew point hygrometer, while the other one uses a conductance type humidity sensor. In both cases the closed chamber measuring method is used. Furthermore, we have applied the same principle of calibration to both instruments.
Keywords: TEWL, dew point hygrometer, conductance type humidity sensor

1. INTRODUCTION

Measurement of the transepidermal water loss (TEWL, expressed in grams per squaremeter and per hour) is used for studying the water barrier function of the human skin [1]. The more perfect the skin protective coat, the higher the water content and the lower the TEWL (Fig.1).

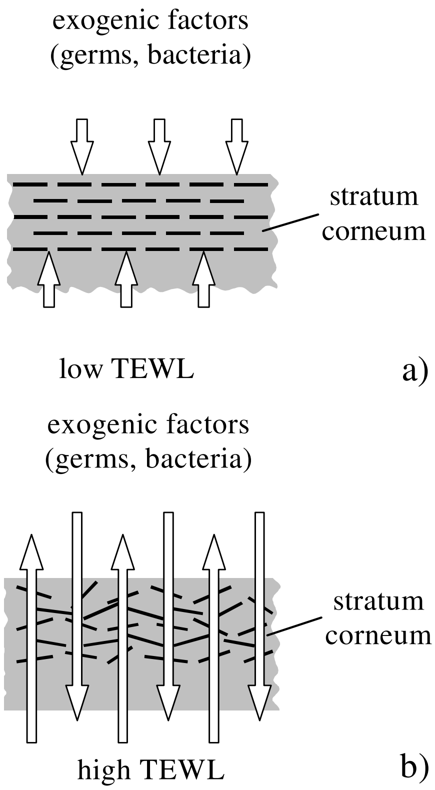

Figure 1. Schematic illustration of the barrier function of the stratum corneum. a) healthy skin , b) disturbed skin.

The outer part of the skin is the stratum corneum which forms a barrier against diffusion of water and is also an effective barrier for microbes and chemical substances. The stratum corneum contains much water and is flexible in the healthy state, but it becomes hard and brittle when dehydrated. Disorders such as atopic dermatitis arise when this barrier function does not work properly.

Several techniques have been developed to measure the skin properties that are influenced by the water content. One possibility is the measurement of the transepidermal water loss of the skin.

TEWL measurements allow to discover disturbances in the skin protective function in an early stage, even before they are visible. Normal skin allows water loss only in small amounts. In the case of atopic skin the water loss is much higher. The determination of the TEWL is an important support to investigate the skin irritation that occurs by various physical and chemical influences. Typical fields of application are allergic tests, occupational medicine, observation of the newborn, supervision the healing process of skin damages and burns or testing the effectiveness and biocompatibility of cosmetic products. Different methods for TEWL measurement from local skin sites have been described: Closed chamber methods and open chamber methods [2].

2. OPERATING PRINCIPLES

In this paper we report on two novel TEWL instruments based on the closed chamber method. The microsensor is placed in a housing which forms a closed measuring chamber after touching the skin. The water vapour emitted from the skin fills the small measuring chamber and causes an increasing relative humidity inside the chamber. The growing rate of the humidity is a measure for the TEWL value of the skin. Some recovery time is necessary after each measurement. The sensor chip must have enough time to try up and to reach its initial condition before starting a new measurement.

The first instrument (later on called instrument A, Fig.2) is based on a ceramic chip carrying an interdigital electrode structure which is covered by a hygroscopic anorganic salt film.

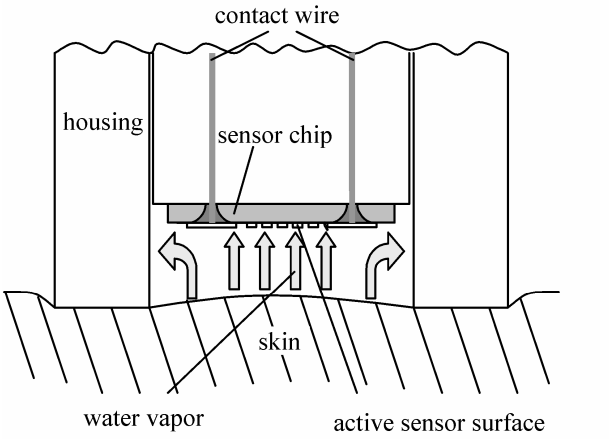

Figure 2. Schematic cross section of the measuring head of the instrument A (conductivity method).

The main sensing effect used in this instrument is the conductance change of the hygroscopic film represented by the real part of the admittance [3-5]. The measuring frequency is 500 kHz. The admittance Y is measured by using a Precision LCR Meter. Furthermore, it is necessary to measure the relative humidity RH of the ambient air. After a time interval t_m (30 s) starting at the moment of touching the skin the change of admittance (Y_s at the starting time, Y_m after the measuring interval t_m) is recorded. The TEWL value is calculated from t_m, ($Y_m - Y_s$) and RH by using an experimentally determined function.

The second instrument described in this paper (later on called instrument B, Fig.3) is based on a silicon chip, which is mounted on a Peltier couple. The sensing effect of this instrument is the change of the dew point temperature by the emission of water from the skin [6,7].

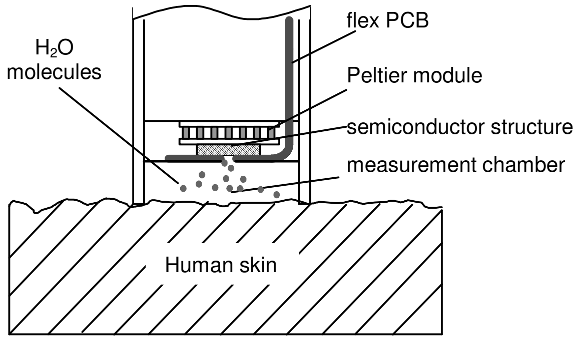

Figure 3. Schematic cross section of the measuring head of the instrument B (dew point method).

At the moment of touching the skin the actual dew point recording process is started. Depending on the humidity value the hygrometer takes about 5 readings (detections) per second. After the time interval t_m (5 s) the dew point temperature T_s is recorded. A value of TEWL is calculated with an experimentally determined function based on T_s and t_m. The algorithm optimizes Peltier couple current and energy injected into the heater to achieve fast detections and to follow humidity changes in the surrounding environment. The hygrometer can measure air humidity in the range from 0 to 30 °C of dew point temperatures with resolution 0.1 °C and accuracy 0.4 °C (with detections of every 0.2 – 0.3 s).

3. TECHNOLOGY

In the case of instrument A a ceramic chip with the dimensions of 5 mm x 5 mm x 0.6 mm is used. The chip is mounted in a distance of about 1.4 mm away from the skin surface. The lead-in wires are guided through funnel-shaped holes to the rear substrate surface (Fig.2). They are bonded to the contact pads of the chip by using an isotropically conductive adhesive. The width of the electrodes is about 55 µm, the gap between interdigital electrodes is approximately 15 µm (Fig.4). The electrodes are made of a double layer of molybdenum (0.2 µm) and gold (8 µm). The molybdenum film is deposited by RF-sputtering. The gold film must be deposited in such a way that it completely and safely covers the underlying molybdenum electrode including side walls. Therefore, the gold film is produced by electroplating. It has an important protective function against chemical degradation. The active moisture sensing area is 1.75 mm x 3.15 mm and is covered with a hygroscopic anorganic salt film.

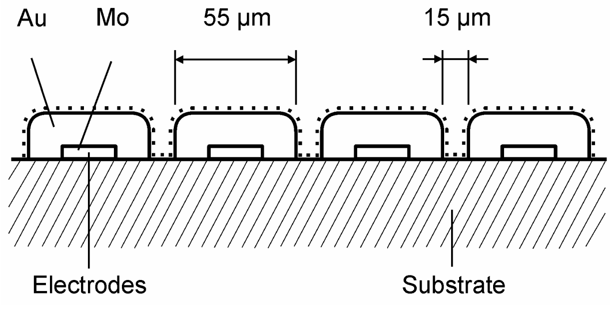

Figure 4. Schematic cross sectional view of the electrode system of the instrument A (conductivity method). Sensing area covered by an anorganic salt film.

In the case of instrument B the hygrometer is based on a silicon semiconductor structure, which contains a dew point interdigital impedance detector (on level II), and thermistor and heater (on level I). The chip face is positioned in a distance of 8 mm away from the skin surface. On the silicon substrate (385 µm thick) the following layers were formed and patterned: thermal silicon dioxide (0.3 µm), gold (0.25 µm as thermoresistor and heater), silicon dioxide (0.6 µm) and gold (0.15 µm) as impedance detector. The impedance detector electrodes pitch was set to 6 µm (Fig.5). The sensitive detector area opened in the flexible PCB is approximately 2 mm x 2 mm. Finally a flip-chip technology was used for electrical structure input/output bonding into flexible PCB ribbon.

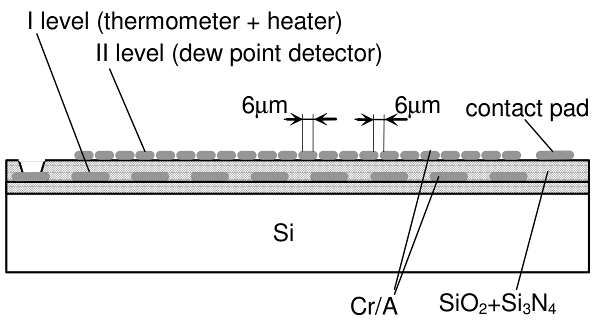

Figure 5. Schematic cross sectional view of the electrode system of the instrument B (dew point method).

4. CALIBRATION

The experimental methods used for the calibration of the instruments A and B are practically the same and differ only in marginal details. To generate a certain TEWL value we have used a small and light vessel containing some water and covered by a semipermeable diaphragm. The water evaporation rate (*ER*) can be calculated from the formula

$$ER = \frac{\Delta m}{A \cdot \Delta t} \qquad (1)$$

with the mass loss Δm in grams, the time interval Δt in hours and the area of the diaphragm A in squaremeter. To determine the water loss the vessel is arranged on a precision balance. First a stable value of *ER* is generated by using a proper diaphragm. Then the TEWL sensor to be tested is placed on top of the diaphragm whereby the sensor head touches the diaphragm forming a closed measuring chamber (Fig.6). The evaporation rate defined by (1) corresponds to the TEWL in case of a measurement on the human skin. Hence the evaporation rate of the calibration configuration is also called TEWL. It is supposed that the evaporation rate is uniformly distributed over the surface of the diaphragm. Different TEWL values can be adjusted either by applying a different number of membrane layers or different types of membrane materials (methods used at WUT). Different TEWL values can also be achieved during a long term drying process of the vessel (method used at VUT).

The instrument A (developed at VUT) has been calibrated at different values of relative humidity of the ambient air in the range from 31 % to 64 %.

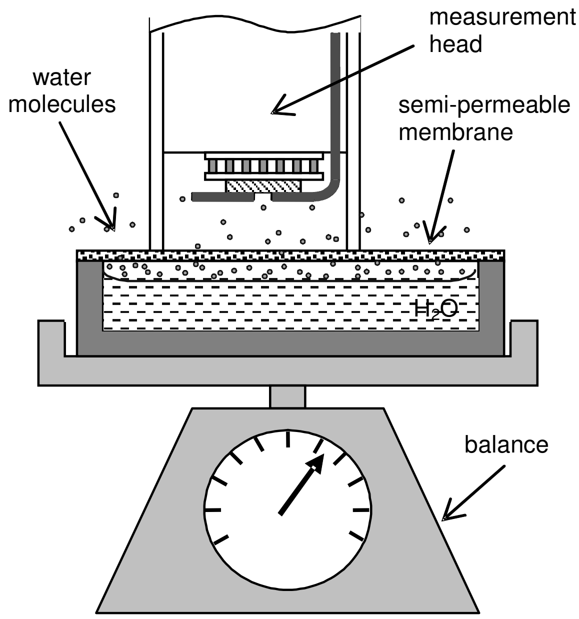

Figure 6. Schematic illustration of a TEWL generator used for the calibration of the instruments.

5. MEASUREMENTS AND RESULTS

Measurements with the two different instruments have been carried out in an office room at a temperature of 25℃ and a relative humidity of 35%.

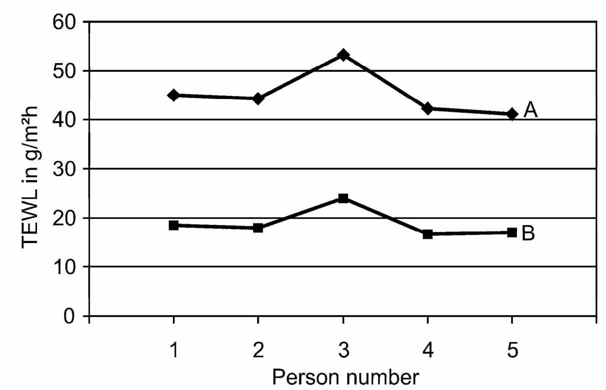

Figure 7. Comparison of measurement results. The upper curve refers to instrument A (conductivity method), the lower curve belongs to instrument B (dew point method).

We have investigated five persons in the age between 19 and 65 years. The measurements were carried out in the crook of the left arm. The test persons have been asked to rest at least 30 minutes before starting the measurement in order to avoid errors caused by perspiration. One characteristic result is shown in Fig.7. The persons (all male) are ordered in their age: person 1: 19 y, person 2: 27 y, person 3: 27 y, person 4: 32 y, person 5: 65 y.

6. DISCUSSION

The results presented in Fig.7 show that both instruments indicate the individual differences in the TEWL value of the investigated persons. It can be clearly seen that the TEWL of subject 3 differs significantly from the other subjects. Furthermore, we find that the old person 5 has a lower TEWL compared with the young person 1. This is in good agreement with results found in the literature [8]. However, the absolute values of the two curves A and B shown in Fig.7 are different. One explanation of the considerable shift is based on a biological effect. With the instrument B the skin sees a rather cold surface during the period of measurement because of the action of the Peltier couple. The dew point temperature is significantly below room temperature. Therefore, the emission of water from the skin will be lower, resulting in a lower TEWL. Another contribution to the shift is the difference in the measuring times (30 s for the instrument A and 5 s for the instrument B) and the non-linearity of the relationship between the air humidity inside the closed chamber and the measuring time.

Measured humidity curves show a part with increasing slope at the begin of the measuring interval followed by a part with decreasing slope which approaches a saturation value. Furthermore, the rate of water evaporation from the skin is not constant during the measuring time. Therefore, further research is necessary to find a way how to define a proper measuring interval. It should also be possible to create new ideas how to calculate a TEWL value from a series of sensor signals (not only from two humidity values at the begin and the end of the measuring interval).

A further question of interest is the influence of the ambient temperature and the ambient air humidity on measuring results. Both quantities do not only have impact on the measuring instruments but also on the measuring subjects itself. TEWL measurements should be carried out in a special room with standard conditions (stable temperature and stable relative humidity). It is also known that the TEWL value depends not only on the type of skin, but also on the emotional condition of a person and of other parameters, like the day time and the season of measurements (differences in summer and winter). Therefore, the medical interpretation of a measured TEWL value is difficult.

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REFERENCES

1. P.G.M. van der Valk, M. Kucharekova, R.A. Tupker, Transepidermal water loss and its relation to barrier function and skin irritation, Chapter 8 in Bioengineering of the Skin. Water and the Stratum Corneum, edited by J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach, Second edition, CRC Press, Boca Raton, 2005, pp. 97-104.
2. V. Rogiers, E. Houben, K. De Paepe, Transepidermal Water Loss Measurements in Dermato-Cosmetic Sciences , Chapter 5 in Bioengineering of the Skin. Water and the Stratum Corneum, second edition, edited by J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach, Second edition, CRC Press, Boca Raton, 2005, pp. 63-76.
3. B. Valentin, M. Mündlein, R. Chabicovsky, J. Nicolics, Evaluation of a Novel Transepidermal Water Loss Sensor, CD-ROM Proceedings of the IEEE Sensors 2004 Conference, Vienna, Austria, October 24-27, 2004, pp. 115-118.
4. B. Valentin, M. Mündlein, R. Chabicovsky, J. Nicolics, A novel microsensor for the measurement of the transepidermal water loss of human skin, Proceedings of the 12th International Conference SENSOR 2005, 10-12 May 2005, Nürnberg, Germany, Vol. I, pp. 173-178.
5. B. Valentin, Untersuchung eines Dünnschicht-sensors zur Messung des transepidermalen Wasserverlusts der menschlichen Haut (Investigation of a thin film sensor for the measurement of the transepidermal water loss of human skin), diploma thesis (in German), 2004, Vienna University of Technology.
6. R. Jachowicz, J. Weremczuk, G. Tarapata, Transepidermal water loss sensor based on fast dew point hygrometer, Sensors and Actuators A 123-124 (2005) 7-11.
7. R. Jachowicz, Dew point hygrometer with heat injection - principle of construction and operation, Sensors and Actuators 7 (1-3), (1992) 455-459.
8. K-P. Wilhelm, M. Brandt, H.I. Maibach, Transepidermal Water Loss and Barrier Function of Aging Human Skin, Chapter 13 in Bioengineering of the Skin. Water and the Stratum Corneum, Second edition, edited by J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach, Second edition, CRC Press, Boca Raton, 2005, pp. 143-158.