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Investigations on a diffusion porometer with a fast humidity sensor

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Summary

A commercially available small humidity sensor with a very fast response has been used in an unventilated dynamic diffusion porometer. Measurements over calibrated dummy resistances show that such a porometer has definite advantages in measurements in the field. Particularly the waiting time before each measurement, necessary to obtain reproducible results with the commonly used LiCl sensor can be shortened from 2 min to 15 s or even less.

It is shown that the theoretical model as adopted by Stigter (1973) can successfully be used to describe the observed phenomena.

Introduction

For the measurement of leaf epidermal resistance in the field, the closed diffusion porometer is the most powerful instrument available today (Kanemasu et al., 1969; Stigter, 1972; Stigter et al., 1973; Slavik, 1974). The instrument is usually equipped with an Aminco LiCl humidity sensor. Stigter (1974) showed that for a ventilated dynamic diffusion porometer the problems related to calibration and to dynamic use of a LiCl humidity sensor can be overcome by means of a well defined calibration and measuring strategy. It was shown (Stigter & Visscher, 1975) that this method also led to excellent results when applied to an unventilated Kanemasu porometer.

A prerequisite of the calibration and measuring procedure is the following. One fixed electrical resistance value of the LiCl sensor is used as an accurately reproducible point of departure. This point has to be maintained, prior to each measurement, during a period of at least two minutes, to eliminate any memory effects of the sensor.

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In field work this procedure is often experienced as circumstantial. It was therefore most interesting to investigate the properties of a porometer, equipped with a small sensor, having a very small response time. The main purpose of the experiments was to examine whether the mentioned waiting time could be shortened. In addition, the results might lead to a better understanding of the theoretical model as used by Stigter.

Materials and methods

The sensor

The HUMICAP sensor is supplied commercially by Vaisala OY, SF-00440, Helsinki 44 (Finland). It is a thin film capacitor with organic polymer dielectric of about 1 μm thick. The dimensions are about 4 mm × 4 mm. The response time was stated to be less than 1 s at an ambient temperature of 20 °C. The measuring range is from 0 to 100 % relative humidity (r.h.).

The porometer cup

For sake of simplicity we decided to use the complete humidity measuring instrument as supplied by Vaisala, including probe and indicating instrument. The probe was mounted concentrically in a cylindrical cup. To minimize the effects arising from adsorption and desorption of water (vapour) by the walls, the cup has been made of polypropylene (Stigter et al., 1973). A perforated membrane with a diffusive resistance of about 0.14 s/cm was placed in the opening to suppress convective flows. The cup volume was 4.56 cm^3 and the opening was 227 mm^2 (diameter 17.0 mm, length 20.1 mm). A thermocouple for measuring the temperature in the cup (copper constantan, 0.1 mm) was mounted close to the sensor. A stream of dry air could be pumped to the cup through a 1 mm stainless steel capillary inserted in the wall of the cup.

The electronic equipment (Fig. 1)

The output of the indicating instrument was 0 tot 100 mV for a measuring range of 0-100 % r.h., at a level of about 7 V to ground. It was led via an impedance transformer and a second-order low-pass filter to a differential amplifier. So finally

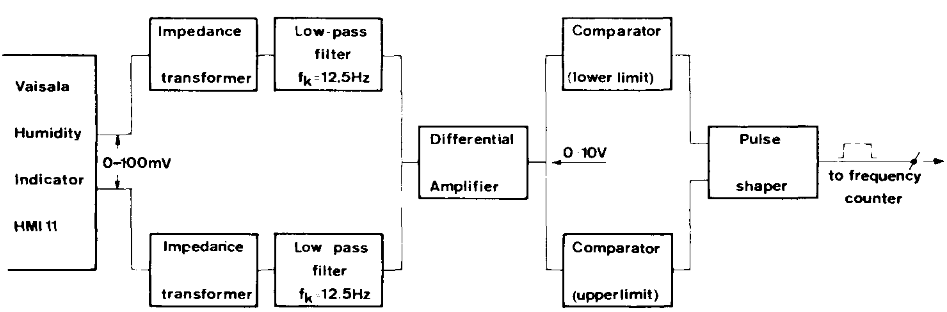

Fig. 1. Schematic arrangement of the electronic circuit used.

Table 1. Nickel pore membranes used.

No	Type	Diffusion resistance (in s cm^{-1}) at 25 °C (R_{25}**)
1	30R	1.20 ± 0.2
2	30T	2.30 ± 0.2
3	15T	5.00 ± 0.2
4	20W	10.60 ± 0.4

* VECO-Zeefplatenfabriek N.V., Eerbeek.
** At temperature x : $R_x = R_{25}/[1 + (x-25)/60]$ with 10 Lx L40.

the output was 0-10 V corresponding to 0-100 % r.h. This signal was led to two comparators. The reference input of each comparator could be set with a ten-turn potentiometer, which enabled to choose the lower or upper limit of the measuring interval. The two signals of the comparators were sent to the inputs of a pulse shaper, resulting in an output pulse (+5 V) during the interval chosen. The pulse width was measured with an electronic frequency counter. This could be done with an accuracy of better than 0.1 %.

The measuring procedure

The porometer was placed over a temperature-controlled filter paper, saturated with distilled water. The temperature of the paper was measured with a thermocouple (copper-constantan, 0.1 mm).

A set of nickel multipore membranes has been used as known diffusive resistances (Table 1), calibrated against a standard set (Stigter & Lammers, 1974). These membranes were mounted in a steel slide between the opening of the cup and the filter paper. By pushing the slide forward the opening could be closed, by pulling it backward the membrane was brought in front of the opening of the cup.

At the start of each cycle dry air was pumped through the cup to maintain the reading at 10 mV for the time chosen. Then the membrane was pulled before the cup opening. Now the time lapse for the reading to increase from 20 to 22 mV (approximately 20 to 22 % r.h.) was measured electronically. These values have been chosen simply because the earlier used LiCl sensor measured about the same interval.

Results and discussion

Waiting time

Table 2 shows a typical result of three successive measurements, when a waiting time of 30 s was exercised. The dimension of the cup and the interval chosen lead to rather short time lapses. The reproducibility is good and it hardly grows worse with a waiting time of 15 s. When dry air is pumped through the cup until a reading of 0 mV (0 % r.h.) is reached, no further waiting is required, to get the same reproducibility.

Table 2. Reproducibility of measurement with a waiting time of 30 s (at 10 % r.h.) and an interval of 20 to 22 % r.h.

Membrane No	Three successive time lapses △t (s)			Average △t (s)	Temperature (°C)	
					surface	cup
without	0.212	0.214	0.213	0.213	24.2	24.8
4	0.977	0.973	0.983	0.978	24.3	24.8
3	0.568	0.566	0.575	0.570	24.3	24.9
2	0.375	0.373	0.377	0.375	24.4	24.9
1	0.293	0.293	0.298	0.295	24.4	24.9
without	0.213	0.209	0.211	0.211	24.5	25.0
1	0.305	0.286	0.294	0.295	24.5	25.0
2	0.373	0.374	0.371	0.373	24.5	25.0
3	0.573	0.567	0.565	0.568	24.6	25.1
4	0.977	0.962	0.981	0.973	24.6	25.1
without	0.205	0.200	0.208	0.204	24.7	25.2

Mean porometer (cup) temperature: 25.0 ± 0.2 °C
Mean surface temperature : 24.5 ± 0.2 °C

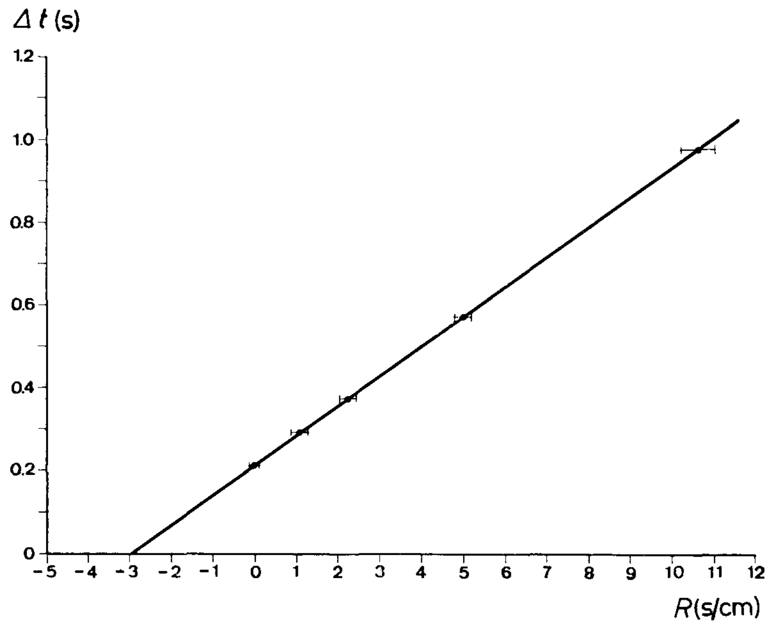

Fig. 2. Calibration time from the results in Table 1. The slope of this line has been used to calculate the apparent volume at 25.0 °C.

Apparent cup volume

A diagram of time lapse against diffusive resistance is shown in Fig. 2. The apparent calibration volume of the porometer is calculated with the following equation (Stigter et al., 1973):

$$\Delta t = K\,(R_1 + R_p) = \frac{V_t}{S_p}(R_1 + R_p) \ln \frac{e_1 - e_p\,(t_i)}{e_1 - e_p\,(t_f)} \qquad (1)$$

where S_p = porometer opening
R_1 = membrane (leaf) resistance
R_p = porometer resistance
e_1 = vapour pressure at the evaporating surface
$e_p\,(t_i)$ and $e_p\,(t_f)$ = vapour pressure at the initial and final limit of the interval, respectively
Δt = time lapse of that interval
K = slope of the calibration lines.

Taking e_1 = 30.739 mbar (3.0739 kPa), $e_p\,(t_i) = 0.20 \times 3.1671$ kPa and $e_p\,(t_f)$ =

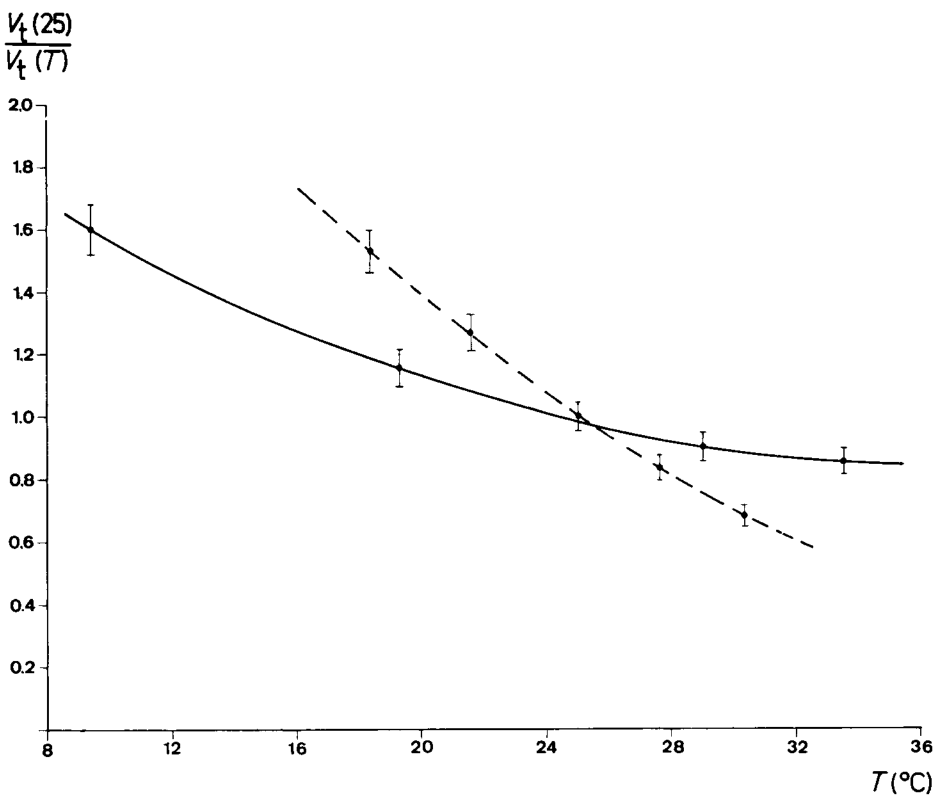

Fig. 3. Dependence of the apparent volume on temperature for LiCl-sensor (- - ● - -) and Humicap sensor (—●—).

Table 3. The same measurements as in Table 2; 4 weeks later.

Membrane No	Three successive time lapses $\triangle t$ (s)			Average $\triangle t$ (s)	Temperature (°C)	
					surface	cup
without	0.214	0.219	0.216	0.216	24.5	25.1
4	1.002	1.025	1.021	1.016	24.6	25.2
3	0.614	0.614	0.607	0.612	24.7	25.2
2	0.397	0.402	0.401	0.400	24.7	25.3
1	0.311	0.316	0.314	0.314	24.7	25.3
without	0.218	0.216	0.219	0.218	24.8	25.3
1	0.308	0.313	0.316	0.312	24.8	25.3
2	0.398	0.394	0.386	0.393	24.8	25.4
3	0.589	0.601	0.597	0.596	24.8	25.4
4	0.996	1.018	1.018	1.011	24.8	25.5
without	0.216	0.216	0.218	0.217	24.9	25.5

Mean porometer temperature: 25.3 ± 0.2 °C
Mean surface temperature : 24.7 ± 0.2 °C

= 0.22 × 3.1671 kPa, it follows from the results in Table 2 and Fig. 2 that V_t = = 6.3 ± 0.3 cm³.

So the apparent volume at 25.0 °C is 1.4 times the geometrical volume of the cup. Stigter found for his (ventilated) polypropylene porometer factors which changed in the course of time from about 3 to 6 (at 25 °C). Factors of the (unventilated) TFDL porometer after Kanemasu have been found to be 20 to 30, probably due to the relatively large humidity sensor.

Temperature dependence of V_t

Series of measurements at different porometer temperatures led to the results in Fig. 3. The value of V_t at 25.0 °C is considered as unity. For comparison a typical line of the TFDL/Kanemasu porometer has been drawn (Stigter & Visscher, 1975).

The temperature dependence of V_t at 25 °C for the new porometer is about 2.2 % °C^{-1} against 7.1 % °C^{-1} for the Kanemasu type. So the effect of temperature on the final result turns out to be less critical.

V_t in the course of time

During a period of 4 weeks the measurements of Table 2 have been repeated every second day. The results of the last day have been given in Table 3. The calculated value of the apparent volume from these results is V_t = 6.5 ± 0.3 cm³. During these weeks the porometer resistance, at the abscissa in Fig. 2, did not change noticeably, and there were no sudden changes in V_t.

Conclusions

– A porometer with a small HUMICAP sensor is a valuable addition to the range of instruments available for the measurement of the transpiration of leaves. Its ad-

vantage over the (until now) most widely used LiCl sensor is, that the waiting time before each measurement can be shortened from 2 min to 15 s or even less.
– The difference between the 'apparent volume' of the porometer as used by Stigter and the real volume is considerably smaller for the HUMICAP sensor than for the LiCl sensor.
– The apparent volume in measuring and calibration procedures is less dependent on cup temperature.
– The fact that the HUMICAP sensor is not, as the LiCl sensor, a narrow-range sensor makes it more flexible towards measuring problems. The combination of the big advantages of the calibration and measuring procedure as described by Stigter (1974) with this flexibility will be subject of further investigation.

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