AN OSCILLATING PSYCHROMETER FOR MICRO-METEOROLOGICAL PURPOSES

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Summary

A psychrometer is described which is adequately ventilated by oscillating the dry and wet thermocouples with an amplitude of about 1.5 cm and a frequency of about 40 hertz. The temperature and humidity profile is destroyed to a far less extent with this meter than with psychrometers ventilated in the ordinary way. It has been shown that the true vapour pressure of the air is measured by means of an irradiated psychrometer if the dimensions and the reflection coefficients of the dry and wet bulbs are the same.

§ 1. *Introduction*. Thermocouples are widely used to measure psychrometric differences in conditions where relative humidity and temperature change rapidly with time. In order to obtain reliable psychrometric readings it is necessary either to ventilate the thermocouples or to use couples made from wires of very small diameter. By sucking air along the couples the humidity and temperature profile in the air is largely destroyed. Powell[1]) showed that it is not necessary to ventilate the couples if the wire diameter is smaller than 0.017 cm and the diameter of the cotton wire around the wet bulb smaller than 0.007 cm. Such small thermocouples are, however, very fragile. Moreover, if thermocouples are used in series in order to get a larger output, the bulbs cannot be wrapped together in one cotton wire and this complicates the measurement of the humidity.

In this paper a psychrometer is described, comprising robust thermocouples, ventilated by oscillating them with an amplitude of 1–2 centimetres at a frequency of about 40 hertz *). The psychrometric difference measured with these thermocouples is independent

*) Patent applied for.

of the wind velocity. The temperature and humidity profile is destroyed to a considerably less extent with this psychrometer than with psychrometers ventilated in the ordinary way.

§ 2. *The apparatus.* The thermocouples t (see fig. 1) are fixed with a piece of insulator to one end of a 40 cm long steel bar a of 0.18 diameter cm and supported by a copper tube b, which covers the thermocouple wires c. The other end of the steel bar is fixed to the oscillating part of an interrupter d, fed from a dry battery of 4.5 V or a small transformer. If the point of support e and the mass of the couples are properly adjusted, the thermocouples oscillate with a frequency of about 40 hertz and an amplitude of at least 1.5 cm. If a stronger interrupter or an electrical motor is used, the length of the bar can be about one metre, but more points of support must be used; this may be advantageous under some conditions. By means of the screw g at the end of the supporting tube the height of the couples above the soil surface can be adjusted.

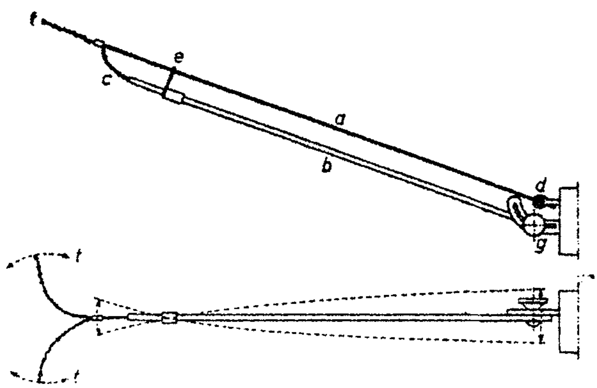

Fig. 1. Principle of the apparatus.
a steel bar, b supporting tube, c thermocouple wires, d oscillating part of an interrupter, e supporting point, g screw to adjust the height of the couples, t thermocouples.

The thermocouples are made of copper and constantan wire with a diameter of 0.04 cm and soldered with tin (e.m.f. = 35.5 μV/°C). The cotton wire has been wrapped around one couple (fig. 2); the length and the diameter of the wet bulb obtained in this way equal

4 and 0.12 cm, respectively. The point of contact of the two wires is at the centre of the wet bulb. The temperature and the psychrometric difference can be measured with only two couples in the air, as is shown in the circuit diagram (fig. 3). For accurate measurements the reference point c is placed in ice and an electronic microvolt meter with a full scale deflection of 30 μV on its most sensitive range is used.

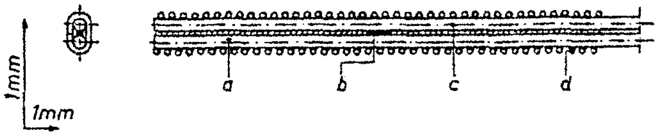

Fig. 2. The wet bulb.
a and c copper and constantan wires, b point of contact of the two wires, d cotton wire.

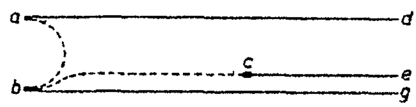

Fig. 3. The circuit diagram.
a wet bulb, b dry bulb, c reference point. The psychrometric difference is measured between d and g, the temperature of the air is measured between e and g.

§ 3. *Measurements.* The influence of the wind velocity on the psychrometric difference was determined in the laboratory, where different wind velocities were obtained by means of a fan. It was found that no influence of the wind velocity could be detected with the most sensitive meters if the bulbs oscillated in the way described above and were situated about 10 centimetres apart. In quiet air, when the bulbs are situated about 5 centimetres apart, some of the air, cooled by the wet bulb, is mixed with the air around the dry bulb. Consequently somewhat lower dry bulb temperatures and psychrometric differences are measured under this condition. Only a slight forced convection eliminates this effect. As no constant humidity room was available, the psychrometric differences obtained with the oscillating meter and an Assmann psychrometer were compared in unconditioned air. It was found that the psychrometric differences obtained with the oscillating meter were somewhat higher than the differences obtained with the Assmann psychrometer as is shown in table I.

TABLE I

Psychrometric differences in °C in an unconditioned room (15.8°C) obtained with an Assmann psychrometer (A) and the oscillating psychrometer (O). Average for A: 6.63, for O: 6.90

A	O	A	O
6.8	7.05	6.7	6.90
6.8	7.10	6.5	6.80
6.7	7.05	6.6	7.00
6.7	6.90	6.4	6.80
6.6	6.75	6.5	6.80

Thus for the oscillating psychrometer the influence of heat exchange by conduction through the solid parts and by radiation is relatively smaller than for the Assmann type. The difference between the psychrometric differences measured in both ways depends of course on the construction of the Assmann psychrometer and the oscillating psychrometer respectively, and need not be the same when compared to other meters. As most psychrometer tables for forced convection are adapted to the Assmann psychrometer, the best procedure is to multiply the measured psychrometric difference by a conversion factor (in this case about 0.96) and to use the standard tables to determine the humidity of the air.

Under the conditions of table I equilibrium was obtained after 10 seconds. In quiet air and in a stream of air flowing with a velocity of 2 m/s the psychrometric difference remained constant during 4 and 2 minutes, respectively. In this time about 30 mg of water evaporated from the wet bulb.

§ 4. *Continuous registration.* A continuous registration of the psychrometric difference with the above instrument is not feasible since the couples are overstrained by continuous oscillating. However, periodic registration, for instance at two minute intervals every quarter of an hour, is possible. Fresh water can be supplied automatically in the way shown in fig. 4. Water syphons between the two flasks a, b through the cotton wire c which is covered with plastic insulator d. Part of this water is conducted to wet bulbs, at different heights along the wire, by means of thin cotton wires between the syphon and the bulbs. As distilled water is always present in the syphon and the dimensions of the small wires e are such that rather more water is transmitted to the bulb than is evaporated, no accumulation of salt is possible.

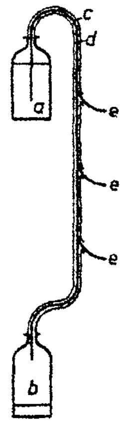

Fig. 4. The wetting system.
a en b flasks with distilled water, c cotton syphon,
d insulator, e cotton wires to wet bulbs.

§ 5. *The influence of radiation.* The psychrometric difference measured by means of an irradiated psychrometer differs in general from that measured with a shielded meter.

However, it will be shown that the vapour pressure, calculated from the temperature of an irradiated dry and wet bulb, equals the vapour pressure of the air if the dry and wet bulb are exactly the same. This condition can be sufficiently realised by using bulbs of the same dimensions and by wrapping a socklet around both the dry and wet bulb, such that the reflection coefficients of the surfaces are the same *).

From the psychrometer theory [2]) and the theory of heat transfer [3]) the following equations are obtained:

$$\theta_w^{(0)} - \theta_d^{(0)} = -\frac{1}{\gamma}\,(\varepsilon_w^{(0)} - e_d), \qquad (1)$$

$$\theta_w - \theta_d^{(0)} = -\frac{1}{\gamma}\,(\varepsilon_w - e_d) + \frac{H_w}{h_w}, \qquad (2)$$

$$\theta_d - \theta_d^{(0)} = \frac{H_d}{h_d}, \qquad (3)$$

*) Patent applied for.

in which γ represents the psychrometric constant, $\theta_w^{(0)}$ the true wet bulb temperature, θ_w the temperature of the irradiated wet bulb, $\theta_d^{(0)}$ the true dry bulb temperature, θ_d the temperature of the irradiated dry bulb, $\varepsilon_w^{(0)}$ and ε_w the saturation pressure at temperatures $\theta_w^{(0)}$ and θ_w and e_d the vapour pressure of the surrounding air, H_d and H_w the heat budgets (that is the difference between incoming and outgoing radiation) of the dry and wet bulbs, respectively, and h_d and h_w the surface coefficients of heat transfer of the dry and wet bulbs. From these equations it follows that

$$e_d = (\theta_w^{(0)} - \theta_d^{(0)})\,\gamma + \varepsilon_w^{(0)},$$

$$e_d = (\theta_w - \theta_d)\,\gamma + \varepsilon_w + \left(\frac{H_d}{h_d} - \frac{H_w}{h_w}\right).$$

Now it is necessary that the vapour pressure calculated by means of the temperatures of the irradiated dry and wet bulb equals the vapour pressure of the air e_d or that

$$e_d = (\theta_w - \theta_d)\,\gamma + \varepsilon_w.$$

This condition is fulfilled if

$$\frac{H_w}{h_w} = \frac{H_d}{h_d}. \tag{4}$$

The temperature rise of the wet bulb, caused by irradiation equals

$$\theta_w - \theta_w^{(0)} = -\frac{1}{\gamma}\,(\varepsilon_w - \varepsilon_w^{(0)}) + \frac{H_w}{h_w}.$$

Since

$$\varepsilon_w - \varepsilon_w^{(0)} = s_w(\theta_w - \theta_w^{(0)}),$$

in which s_w represents the slope of the ε versus θ curve at the temperature $\frac{1}{2}(\theta_w + \theta_w^{(0)})$, this relation can be transformed into

$$\theta_w - \theta_w^{(0)} = \frac{\gamma}{\gamma + s_w}\cdot\frac{H_w}{h_w} = \frac{\gamma}{\gamma + s_w}\cdot\frac{H_d}{h_d} = \frac{\gamma}{\gamma + s_w}\,(\theta_d - \theta_d^{(0)}). \tag{5}$$

Both the temperatures of the dry and wet bulb are higher than the true temperatures of the dry ($\theta_d^{(0)}$) and wet ($\theta_w^{(0)}$) bulb. Consequently the temperatures of the irradiated bulbs cannot be used to determine the relative humidity of the air directly. This value can only be calculated if the true air temperature is determined separately. However, under many conditions the difference between the true air temperature and the air temperature measured with a thermocouple ventilated as described above is small.

For instance, if the diameter of the cylindrical bulb equals 0.2 cm, the heat transfer coefficient of the bulb equals according to McAdams[3]) 0.15 cal/cm^2 min °C, since the average velocity of the oscillating bulbs equals 2.5 m/s. The intensity of direct sunlight is under extreme conditions 1.5 cal/cm^2 min. The heat budget of the bulb is therefore at the maximum $1.5/\pi = 0.48$ cal/cm^2 min, and the temperature rise of the dry bulb at the maximum 1.2°C. Under most conditions the heat budget of the bulbs is much lower than 0.48 cal/cm^2 min. The temperature rise caused by direct radiation from the sun is therefore in many cases smaller than 0.5°C. If the bulbs are shielded against direct sunlight, the differences between the air temperature and the temperature of an oscillating dry thermocouple can safely be neglected.

By means of the same equations (see (5)) it can be proved that the temperature rises of the wet and dry bulbs are the same if the following condition is fulfilled:

$$\frac{H_d}{H_w} \cdot \frac{h_w}{h_d} = \frac{\gamma}{\gamma + s_w}.$$

Under these conditions the psychrometric difference is independent of the irradiation. They can be realised by making the wet bulb somewhat larger than the dry bulb. As s_w depends on the wet bulb temperature, the bulbs can only be adjusted exactly at one temperature. This method of eliminating the influence of irradiation, which was used by Franssila[4]) and Peerlkamp[5]), is therefore less favourable than the method suggested above.

I am indebted to Dr D. A. de Vries for suggestions which led to the quantitative expression of the influence of radiation.

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