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A Net Radiation Instrument with Constant Ventilation

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The first attempt to measure the net radiation was carried out by ALBRECHT [1]. He showed that the net radiation can be obtained by exposing a blackened plate horizontally to the earth's surface and measuring the temperature difference existing through it. The relationship is

$$R_n = [2\lambda + f(v)]\ (T_1 - T_2), \tag{1}$$

where λ is a constant given by the ratio of the thermal conductivity to the thickness of the plate, and $f(v)$ is a variable which is a function of the wind speed, the roughness of the plate, etc., representing the cooling effect of the wind. $T_1 - T_2$ is the temperature difference across the plate and represents the output signal of the instrument.

This equation shows that, to reduce the effect of the wind, λ should be large compared to $f(v)$. This means that the thermal conductivity of the plate should be large and the thickness should be small.

ALBRECHT [1, 2] and FRANSSILA [3] measured the wind effect by adding a known quantity of heat electrically to one of two identical radiation plates. GIER and DUNCLE [4], on the other hand, held the wind function, $f(v)$, constant by exposing the plate to a strong jet of air from an electric blower and nozzle. The latter method requires that the wind function, $f(v)$, should be equal on the two sides of the plate, a feature not too easy to obtain in practice without some adjusting device. The instrument described in this paper has a specially designed vane in the nozzle throat and an electric heater on the radiation plate to furnish a sensitive control of the ventilation, so that ventilation on each side of the plate can be accurately equalized.

Figure 1 illustrates the construction of the instrument. *B* is a blower driven by a 1/8 horse power electric motor. *N* is the nozzle made of lucid and *V* is the adjustable vane for controlling the ventilation. Experiments showed that the sensitivity of the control was strongly affected by the shape of the vane as well as by the intensity of the turbulence of the jet

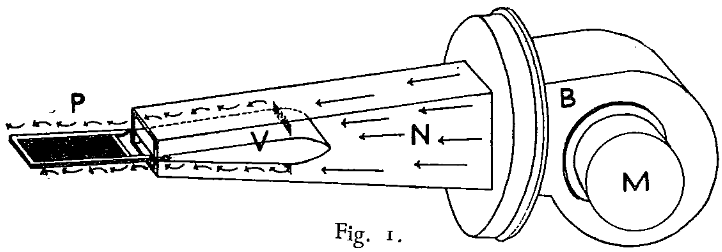

Fig. 1.

itself. Best results were obtained with a streamlined vane on the leading edge of which was mounted a grid of 2 mm diameter cylinders which created the necessary turbulence. *P* is the radiation plate. It is furnished with a termopile for measuring the temperature difference, $T_1 - T_2$, across the plate, and a resistance coil via which an equal amount of heat can be added to each side of the plate.

Now let the plate be shielded from external radiation and an equal amount of heat be added to each side of the plate. Then let the position of the vane be adjusted to make $T_1 = T_2$. It is easy to show that when the vane is adjusted the ventilation function is equal on the two sides of the plate. This method is exact only if the radiation plate is symmetrical. The error calculation shows, however, that in practice an asymmetry of 5—10 % can be tolerated.

This method assumes that the ventilation is constant. It is clear, however, that unless a constant speed electric motor is used for the blower, any change in the supply voltage will cause a corresponding change in the blower speed. Measurements made to determine the error of the net radiation indicated, when the ventilation was not constant, showed that a 10 % change in the supply voltage for the D.C. blower motor will induce less than 1 % change in the net radiation indicated.

The effect of wind upon the instrument was investigated both in the laboratory and in the field. For wind speeds up to 4 m sec^{-1} there was no effect on the reading of the instrument. At a wind speed of 12 m sec^{-1}

there was no effect on the calibration, provided that the air jet pointed downwind. An increase of 0.3 % resulted when the air jet was orientated upstream. The largest effect came with a crosswind. The calibration increased 2 % for a crosswind of 12 m sec^{-1}. Apparently a strong crosswind deflects the air jet off the plate.

The radiation plate was made of a glass microscope slide of dimensions 0.11 cm x 2.5 cm x 7.5 cm. Glass was chosen because of its relatively high and stable thermal conductivity properties among electrical insulators as a class. The thermopile was constructed by winding 120 spaced turns of 0.12 mm diameter constantan wire around the slide. Thermocouples were formed by electroplating copper on the constantan wire after the method of WILSON and EPPS [5]. The plate was immersed in the plating solution, so that half of each turn of constantan wire was plated until the copper deposit had approximately twice the diameter of the constantan wire. The resistance of the thermopile was 120 ohms. A heater coil of 7.5 ohms was constructed by winding 120 turns of silk-covered copper wire of 0.12 mm diameter between the thermocouple wires. The paint with which the radiation plate is blackened has to have an absorptivity which is constant for all wavelengths. The blackening agent used on this instrument was a paint available commercially as Fuller's velvet decoret. GIER and DUNCLE show that this paint has an absorptivity of about 0.93 for wavelengths from 0.4 to 2.5 μ, the band representing 96 % of the solar energy received at the earth's surface. The average absorptivity for longwave radiation from 10 μ to 15 μ is about 0.88.

Since most of the solar energy received at the earth's surface is in the 0.4 to 2.5 μ band, the instrument will read about 6 % too low for long wave radiation, because the absorptivity here is only about 0.88 compared to 0.93 for solar energy. Most of the error due to this fact can be eliminated by calibrating the instrument separately for short wave and long wave radiation.

In this connection it is to be noted that it may still be possible to find a more suitable blackening substance for the plate. For instance, lamp soot in amber laquer, which has, according to Albrecht an absorptivity of 0.98, might be better than the paint which we used.

The upper and lower surfaces of the radiation plate are not flat, but ribbed, on account of the painted thermopile and heater wire coils. It might be objected that the cosine law would not be valid, but measurements made at different sun angles showed that, within the limits of measurement errors, the calibration was independent of the sun angle. Therefore it does not seem necessary to cover the ribbed surfaces with smoothing plate. Very likely the ribbed surface tends to subdue any discontinuity in sensitivity, which might arise from a critical reflection angle. The air jet reduces the microfluctuations considerably. At noon on a clear day in summer with the wind less than 12 m sec^{-1} the microfluctuations are less than 1 %.

The instrument responds to 100 % of the change in radiation within 5 seconds, provided that the position of the vane is properly adjusted. But if the ventilation is not equal on the two sides of the radiation plate, the lag of the instrument is increased from a few seconds to about one minute. The radiation plate must attain a new equilibrium temperature before it indicates a steady value. When the ventilation is not properly balanced, the radiation indicated is also a function of the plate temperature. This result is to be expected from the theory and can be further verified by applying heat via the heat coil. When the ventilation is equalized, there is no change in the reading of the instrument when heat is applied. In fact, this latter procedure constitutes a test of whether or not the instrument is adjusted properly during normal operation. When the ventilation is properly equalized, a change in the sign of the radiation flux is reflected by a similar change in the sign of the temperature difference, but with no change in absolute value. The former can be simulated by inverting the instrument, providing that the radiation balance is steady. A suitable quick change mount was constructed specifically for the test. It is clear that the vane can also be properly positioned by this reversal procedure after a series of approximate settings. Both methods give similar results.

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A more detailed description of the instrument will be published later.

REFERENCES.

1. ALBRECHT, F., 1933: Ein Strahlungsbilanzmesser zur Messung des Strahlungshaushaltes von Oberflächen. *Met. Zeitschr.*, 50, 62—65.
2. —»— 1949: Betrachtungen über die Konstruktionsgrundlagen von Strahlungsumsatzmessern und Beschreibung einer einfachen Form dieses Gerätes. *Arch. Met. Geophys. und Bioklimat. Serie B*, 1, 373—387.
3. FRANSSILA, M., 1936: Mikroklimatische Untersuchungen des Wärmehaushalts. *Mitt. Met. Zentralanst., Helsinki*, No 20, 104 pp.
4. GIER, J. T. and R. V. DUNKLE, 1951: Total hemispherical radiometers. *Transact. Amer. Inst. Electr. Engin.*, 70, 5 pp.
5. WILSON, W. H. and T. D. EPPS: *Proc. Phys. Soc. London*, 32, p. 326.