551.508.21

A NEW APPROACH TO PYRANOMETER CALIBRATION

1. There are several radiation parameters in short wave range such as global, direct, diffuse and reflected irradiances, which are measured in radiation network of India and other countries. Direct irradiance is measured by pyrheliometers. Several types of self-calibrating pyrheliometers have been developed to provide an absolute measurement of direct irradiance. World Radiation Centre (WRC), Davos maintains a group of such highly stable self-calibrating absolute radiometers of different types called World Standard Group of Instruments (WSG). The average direct irradiance

measured by this group of radiometers is considered as World Radiometric Reference (WRR). The WRR is accepted as representing true direct irradiance with an accuracy of better than ±0.3 percent. It was adopted by the WMO congress in 1979 and has been in effect since 1st July 1980. The WSG is inter-compared at least once a year to ensure stability of all the radiometers in the group. During International Pyrheliometer Comparisions (IPC), organized every five years by World Radiation Centre at Davos, the standard pyrheliometers of Regional Centres are compared with the WSG, and their calibration factors are adjusted to WRR, if required. They, in turn, are used to calibrate the network instruments.

Unlike the case of a pyrheliometer, no absolute self-calibrating pyranometer have been designed. There are various methods for calibrating a pyranometer as mentioned in WMO (1983). They are described below along with their limitations and sources of inaccuracies.

2. *Existing methods of pyranometer calibration* - (*i*) *With reference to a standard pyrheliometer* - The pyranometer under calibration and a standard pyrheliometer are simultaneously exposed outdoor to solar radiation. The direct component is eliminated alternately from the pyranometer by shading its outer dome with a disk of sufficient size mounted on a thin rod and held some distance away to subtend a solid angle not more than 5°. In principle a comparison is made between the computed vertical component of the solar irradiance as measured by the pyrheliometer and that measured by the pyranometer in fully exposed and shaded conditions.

Subtraction of the output during shading interval from the corresponding output during exposed interval yields a value v in μV, which is proportional to the projection of direct solar radiation S on a horizontal surface. Thus,

$$S.\sin\theta = v / k$$

$$k = v / S.\sin\theta$$

Where,

S = Direct solar irradiance at normal incidence measured by the standard pyrheliometer (Wm^{-2})

v = Difference output signal of the pyranometer (μV) under fully exposed and shaded conditions.

θ = Solar elevation angle at the time of measurements.

k = Sensitivity of pyranometer under calibration ($\mu V\, W^{-1}\, m^2$)

Since the exposed and shaded measurements on pyranometer cannot be conducted simultaneously, there are two main sources of inaccuracies :

The first one is due to the approximation of output during shaded condition from the mean of two consecutive measurements of pyranometer outputs in shaded position. Since it takes about three minutes to attain an equilibrium condition each time when the pyranometer is shaded or exposed, it is obvious that the time gap between two consecutive measurements of diffuse irradiance is of order of ten minutes. The computation is based solely on the assumption that the mean value of diffuse irradiance represents the actual diffuse irradiance available at the time of measuring the global irradiance. This requires highly stable sky conditions and a very steady increasing or decreasing trend in diffuse radiation, which is difficult to obtain under natural conditions at most of the places. Thus, there is always a chance of errors.

The second source of inaccuracy is again due to approximation of solar elevation angle θ as this changes a little during the interval, this process takes to complete one set of measurements.

(*ii*) *With reference to a standard pyrheliometer and shaded pyranometer* - In principle, this method is similar to the preceding method except that the pyranometer being calibrated always remains in fully exposed condition to measure global irradiance. Here the vertical component of the direct solar radiation is again determined by the pyrheliometer but the diffuse radiation is measured by a second pre-calibrated pyranometer which is continuously shaded from the direct sun. Thus,

$$S.\sin\theta + v_d / k_d = v / k$$

$$\text{or}\quad k = v / (S.\sin\theta + v_d / k_d)$$

Where,

S = Direct solar irradiance measured by the standard pyrheliometer (Wm^{-2}).

v = Output signal of the pyranometer (μV) to be calibrated under fully exposed condition.

v_d = Output of the shaded pyranometer (μV).

θ = Solar elevation angle at the time of measurements.

TABLE 1

Pyranometer make, model and No.	Calibration constant obtained using shading – unshading method			Calibration constant obtained using new proposed method		
	No. of sets	Mean value of k	Standard coefficient of dispersion(σ/k)	No. of sets	Mean value of k	Standard coefficient of dispersion(σ/k)
Kipp & Zonen CM-5 No.1154	34	10.72	0.011	37	10.76	0.008
Kipp & Zonen CM-5 No.1039	34	11.94	0.010	37	11.91	0.008
Kipp & Zonen CM-11 No.76	16	5.07	0.016	34	5.14	0.008
Eppley PSP No.11919F3	20	9.39	0.014	34	9.37	0.014

Eppley NIP pyrheliometer No.5799A was used in these calibrations.

k = Sensitivity of pyranometer under calibration (μV W^{-1} m^2)

k_d = Sensitivity of shaded pyranometer (μV W^{-1} m^2)

(*iii*) *With reference to a secondary standard pyranometer* - The pyranometer under calibration and a secondary standard pyranometer are mounted horizontally, side by side, outdoors for a sufficiently long period to operate simultaneously. If the instruments are of the same type, only a day or two of measurements should be sufficient. The more pronounced the difference between the two types, the longer the period of comparison must be.

The derivation of calibration factor is straightforward. If R is the mean value of ratio of the outputs of test pyranometer to that of the standard pyranometer, then

$$k = R.\, k_S,$$

where

k = Sensitivity of pyranometer under calibration (μV W^{-1} m^2)

k_S = Sensitivity of the standard pyranometer (μV W^{-1} m^2)

The second and the third procedures described above use another pre-calibrated pyranometer. Hence both these are not the basic methods. The derived value of constant is strongly dependent on the characteristics of the calibrated pyranometer.

3. *New approach to pyranometer calibration* - This method facilitates calibration of two pyranometers simultaneously. Two pyranometers under calibration are mounted horizontally, side-by-side, one for measurement of global irradiance and the other for measurement of diffuse irradiance. Both the measurements are made as frequently as possible, say every five minutes, from sunrise to sunset for solar elevations higher than 20°. The next day, pyranometers are interchanged in their roles and similar measurements are made at same timings. The direct irradiance is also measured simultaneously using a secondary standard pyrheliometer mounted on a solar tracker. Thus, global, diffuse and direct irradiance measurements are made simultaneously.

In principle a comparison is made between the computed vertical component of the solar irradiance as measured by the pyrheliometer and that measured by the two pyranometers, one in fully exposed condition and another in shaded condition. Thus, for any instant on first day, the relation among global, diffuse and direct irradiance yields-

$$v_{1g}/k_1 - v_{2d}/k_2 = S_1.\, \sin\theta_1 \quad (1)$$

Similarly, for any instant on second day, we have

$$v_{2g}/k_2 - v_{1d}/k_1 = S_2.\, \sin\theta_2 \quad (2)$$

where,

v_{1g} and v_{2g} are the output of the two pyranometers in exposed condition (μV).

v_{1d} and v_{2d} are the output of the two pyranometers in shaded condition (μV).

S_1 and S_2 are the direct solar irradiances at the corresponding instants (Wm^{-2})

θ_1 and θ_2 are the solar elevation angles at the corresponding instants.

k_1 and k_2 are the sensitivities of the two pyranometers ($\mu V\ W^{-1}\ m^2$)

Eqns. (1) and (2) are the two linear equations with two unknowns k_1 and k_2. Thus, solution of each set of such equations can provide the values of k_1 and k_2. We can have many sets of such equations from the two days of measurements taken using the standard pyrheliometer and the two pyranometers under calibration. Normally, the pair of equations is chosen in such a way that θ_1 and θ_2 are almost equal so as to calculate k_1 and k_2 at different elevation angles. Thus, this method can also be used to precisely study the angular dependence of k_1 and k_2 as well.

4. Four pyranometers were calibrated using the existing shading/unshading method and also using the new method proposed in this paper. The mean values of k are almost the same while there is improvement in standard coefficient of dispersion (σ/k). The results are tabulated in Table 1. Direct irradiances were measured using standard NIP pyrheliometer.

5. It is worth mentioning that this method does not make use of any other reference pyranometer and also there is no approximation involved in Eqns. (1) and (2). Thus, on the basis of theoretical as well as practical considerations, this provides another basic method for pyranometer calibration. This ensures an easy and more accurate method for simultaneous calibration of two pyranometers with reference to a standard pyrheliometer. If a multi-channel data acquisition system is used more number of pyranometers can be calibrated simultaneously with the same accuracy.

6. The authors are grateful to Dr. R. D. Vashistha, Director (Instruments) of the Surface Instruments Division of India Meteorological Department, Pune for providing necessary infrastructure, inspiration, encouragement and useful guidance. Thanks are also due to the radiation staff who assisted in experimenting to validate the process.

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(*11 August 2004, Modified 26 October 2004*)