TWO THERMISTORS LOW-COST PYRANOMETER

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Abstract

A low-cost pyranometer operating with two thermistors, useful for measuring mean daily global solar radiation, is presented. The simplicity of its design and construction makes this equipment adequate for didactical applications, as well as for insolation measurements requiring medium precision. For these applications this thermistor pyranometer can be used instead of much more costly commercial equipments.

1. INTRODUCTION

Developing countries in low and mid latitudes have in solar energy an important alternative energy-source. The growing interest in the use of solar energy has led to the development of concentrating and storing solar energy systems, for applications going from the generation of great amounts of the electrical energy [1], to domestic water heating. To design these solar systems it is necessary to quantify the insolation levels exiting while testing the operation of the systems. However, in spite of the need of solar systems of all kinds, most of these countries do not have solar radiation data at a sufficient number of stations [3, 4], and the high cost of the commercial pyranometers constitutes a hindrance for laboratories, designers and manufacturers, to adequately test their equipments [5].

In the present communication we show that an easy-to-make, sufficiently accurate pyranometer of an extremely low cost can be constructed using only two thermistors, a round-bottom flask, a voltmeter and 10V-power supply. The operation of this thermistor pyranometer is compared with a commercial one (an Epply PSP pyranometer), and the results obtained with both instruments are shown to be very similar.

2. THE THERMISTOR PYRANOMETER

To construct this low-cost pyranometer, a round-bottom flask of 500 ml containing two thermistors was used. The flask was place horizontally, and its interior was divided into two symmetrical hemispheres by a horizontal sheet of white paper supported by a thin wooden bar. As sunlight absorbers, two aluminum cylinders (diameter = 1.75 cm, height = 0.70 cm) blackened whit smoke were fixed to the wooden bar, one in the upper hemisphere of the flask, and the other in the lower hemisphere. The upper cylinder is thus exposed to the sunlight, while the lower one remains in the shadow. A thermistor was attached to each of the cylinders, and the four wires connected to the thermistor leave the flask through a rubber plug.

To calculate the irradiance it is necessary to know the temperatures T_1 and T_2 of the cylindrical absorbers. Those temperatures can be determined if we measure the resistances R_1 and R_2 of the upper and lower thermistors, respectively. In order to do so, both thermistors were connected in series with an additional resistance (R_3 = 2000 Ω) and a 9.998 V power supply, which were placed outside the flask, as shown in Fig. 1. Then by measuring the voltages V_i (i = 1,2,3), it is possible to calculate the current $I = V_3/R_3$ flowing through the circuit, and the values of the resistances $R_i = V_i/I$ of the thermistors. Once these resistances are known, the temperatures T_1 and T_2 of the two cylindrical absorbers can be calculated by means of the equation [6]:

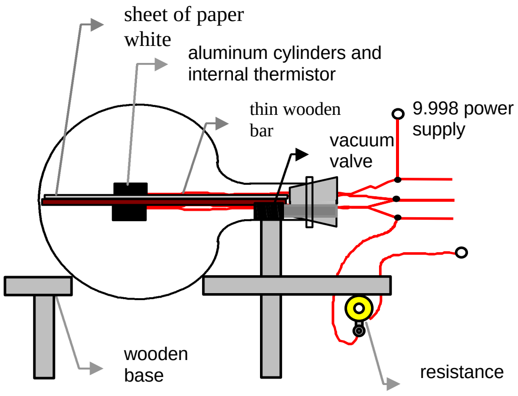

Figure 1. Thermistor pyranometer.

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$$R_i = R_{i,0}\, e^{\beta_i / kT_i} \tag{1}$$

where $R_{i.0}$ is the resistance of the i-th thermistor when $T_i \to \infty$, and β_i is a constant which characterizes it. The values of the constants $R_{i.0}$ and β_i were found to be $R_{1,0}$=0. 0128 ± .0006 Ω, $R_{2,0}$=0. 0112 ± .0004Ω, β_1= 3932 ± 67 J and β_2 = 3974 ± 45 J

To calculate the irradiance I_0 we will apply the following equations, which describe the energy balance corresponding to the upper and lower aluminum absorbers, respectively:

$$m_1 c_1 \frac{dT_1}{dt} + \alpha_1 (T_1 - T_s) = I_0 \tag{2}$$

$$m_2 c_2 \frac{dT_2}{dt} + \alpha_2 (T_2 - T_s) = 0 \tag{3}$$

When m_i, c_i and T_i are the mass, the specific heat, and the temperature of the i-th absorber, and T_s is the temperature of the surroundings. The first term in each of the Eqs. (2) and (3) describes the change of the internal energies of the absorbers, while second term is a linear approximation of the energy transfer due to the combined effect of convection, conduction and radiation [7]. As both absorbers are identical, we have $m_1c_1 = m_2c_2 \equiv k_1$ and $\alpha_1 = \alpha_2 \equiv k_2$, and therefore, subtracting (3) from (2) we obtain:

$$I_0 = k_1 \left(\frac{dT_1}{dt} - \frac{dT_2}{dt} \right) + k_2 (T_1 - T_2) \tag{4}$$

In the following section we will compare the values of the irradiance calculated with this equation (and using the values of T_1 and T_2 of our thermistor pyranometer), with the measurements obtained with an Eppley PSP pyranometer.

3. EXPERIMENTAL RESULTS

To test the operation of the termistor pyranometer described in the past section, we compared the measurements taken with this instrument with those obtained with an Eppley PSP pyranometer. The measurements obtained with both instruments were registered every minute with a Keithley KDAC500 data acquisitor.

As the response time of the commercial pyranometer is very small (less than 20 s), the sequences of measurements obtained with this instrument presented fluctuations. Therefore, in order to slightly smooth these fluctuations, the original sequences of measurements $\{S_n\}$ were replaced by new sequences of data $\{S_n'\}$, obtained by calculating a moving average over three minutes. In other words, the new values S_n' were calculated according to the equation:

$$S_n' = \frac{1}{3} \sum_{k=0}^{2} S_{n-k} \tag{5}$$

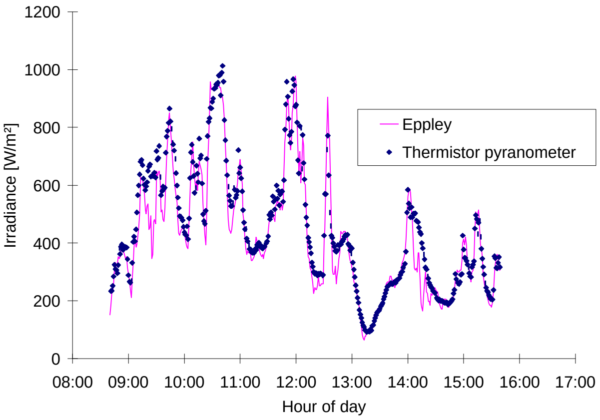

Figure 2. Irradiace measurements, Ago 14.

In Figs. 2 and 3 we can observe the irradiance measurements obtained with both instruments (the thermistor pyranometer and the Eppley one) on August 20 and 14. To calculate the irradiance with the thermistor pyranometer, we optimized the values of the constants k_1 and k_2 appearing in eq. (4) by a least square procedure. The calculated values were: k_1 = 3730 J/(m² °C) and k_2 = 45.1 W/(m² °C). The standard deviation corresponding to the measurements shown in Figs. 2 and 3 was equal to 75 W/m². As we can see in these figures, the irradiance measurements obtained with the thermistor pyranometer and the eq. (2) are very similar to the Epplys measurements.

In Figs. 3 and 4 it is shown the comparison between the irradiance calculated considering the change of the internal energy and the irradiance calculated neglecting it, as in the standard procedure. The first calculation shows a better agreement than the second with respect to the Eppley's values. This procedure compensates the large thermal inertia of the absorber, compared with that of Eppley, by adding the energy absorbed in the heating to that used in the thermal losses, so the graphs resembles more that of the Eppley pyranometer. The integral of the radiation is the same, because in the integration the positive and negative terms compensate.

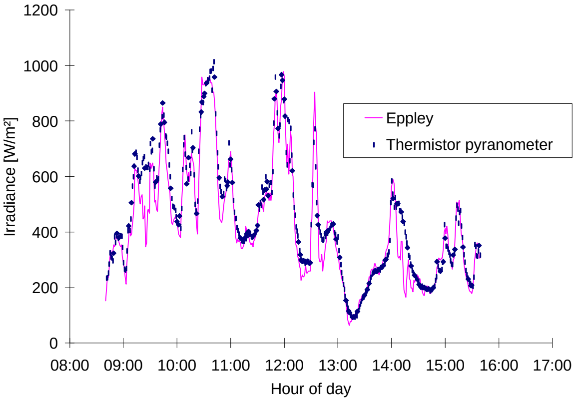

Figure 3. Irradiace measurements, Ago 20.

4. FINAL REMARKS

The results shown in the past section indicate that the low-cost thermistor pyranometer presented in this communication constitutes a possible alternative to more expensive commercial pyranometers to obtain solar radiation data in developing countries. The main drawback of this thermistor pyranometer is its slow response. However, the results shown in Fig. 5 indicate that the differences due the response can be reduced upon considering the changes of the internal energy. This pyranometer can be used for measuring daily mean (or daily total) radiation data, which is the basic information which is sought in a network of solar measuring stations. As the maximum error in the mean values obtained with this low-cost pyranometer was found to be 5% (in comparison with the Eppley's results), this instrument can be classified as a second-class pyranometer, since the World Meteorological Organization considers that the maximum error in daily total radiation data is 10 % for second class pyranometers [8]. If we consider that the meteorological stations in some developing countries are still equipped with third-class pyranometers, with errors as high as 20% for daily total radiation values [9], we can realize that the low-cost thermistor pyranometer presented in this paper is in fact a possible alternative for developing countries. Moreover, the response time of the thermistor pyranometer can be significantly reduced if smaller alumminum absorbers are used.

It should also be observed that the simplicity (and the low-cost) of the thermistor pyranometer presented in this communication allows this instrument to be constructed and used by high-school (and even junior high-school) students, and consequently the network of schools in developing countries could be considered as potential networks of solar measuring stations.

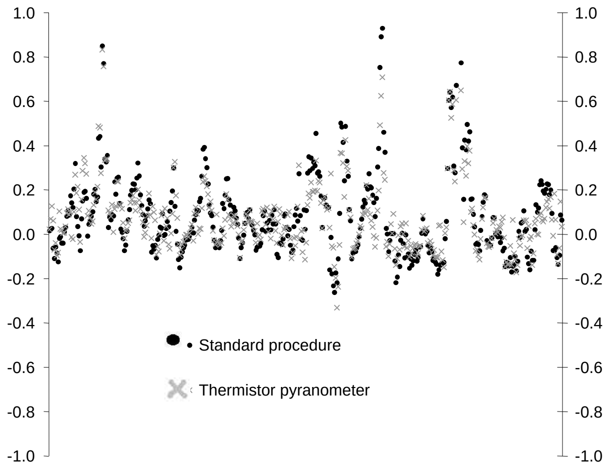

Figure 4. Irradiace comparison, Ago 14.

REFERENCES

1. W. Stine and R.Diver, *A Compendium of Solar Dish/Stirling Tecnology*. Sandia National Laoratories USA, (1994).
2. B. J. Huang and C.T. Hsieh, Solar Energy, **35**, 31-43 (1985).
3. F. Drake and Y. Mulugetta, Solar Energy **57**, 205 (1996).
4. D. Schulze–Kegel and F. D. Heidt, Solar Energy, **58**, 77 (1996).
5. P.T. Tsilingiris, Applied Energy **45**, 283 (1993).
6. W. Crawford, *An Introduction to Semiconductors*, Jhon Wiley & Sons, New York, (1957).
7. H. P. Holman, *Heat Transfer*. (Mc Graw Hill, New York), 1981.
8. World Meteorological Organization, *Guia de Instrumentos y métodos de ob Observación Meteorológicos* , translation of the 5 th , English edition.
9. Estevez y C. de la Rosa, Solar Energy **42**, 9 (1989).