DESIGN, CONSTRUCTION AND CALIBRATION OF A RADIANT HEAT DETECTOR

BY

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Abstract

A detector of heat radiation, designed and constructed with local materials is presented. The instrument is calibrated and the performance studied. The detector consists of 100 hot junctions and 100 cold junctions. The hot junctions are mounted on a flat plate collector and exposed to the radiation to be measured, while the cold junctions are shielded from the direct incident radiation. The thermo junction e.m.f of the incident radiation. The instrument is measured on a modified potentiometer; this gives a measure of the instrument detects both the infra-red radiation and the heat energy associated with the visible range of spectrum. The detector is cheap, sensitive and particularly suitable for detecting the radiant heat from the sun.

Introduction

One of the earliest attempts at detecting radiant heat was made in the year 1800AD when Herschel blackened the bulb of a sensitive thermometer and used it to explore a beam of sunlight passed through a triangular prism. He discovered that the column of mercury always rose whenever the thermometer bulb came in contact with any of the components of the visible light dispersed by the prism. That was what he expected anyway.

What he did not expect was the observed fact that the column of mercury also rose even in the dark portion a little beyond the red component of the spectrum, he rightly concluded that the sunôs energy was also carried by same universal rays. Today, it is well known that the universal ray which Herschel detected nearly 210 years ago is the infra-red radiation. As the thermometer with a darkened bulb turned out to be a sluggish and insensitive detector of radiant heart. Sir Langley devised, in 1881AD a satisfactory heart detector. This detector, known as Bolometer, consists of a long thin strip of a blackened platinum foil bent into a compact zigzag formation. When radiant heart falls on the strip the electrical resistance increases. This increase which can be measured on a Wheatstone bridge, gives a measure of the incident radiant heat.

However, as early as 1822AD Seebeck had found that if a plate of bismuth was connected between two copper wires leading to a sensitive galvanometer, and if one of the copper ï bismuth junctions was kept cool, then a current flowed through the galvanometer. It is now well established fact that thermoelectric current always flows whenever the junctions of any two dissimilar metals are maintained at different temperatures, each pair is called a thermocouple and a series of combination of thermocouples forms a thermopile (Nelkon 1984).

In this study, use is made of the properties of the thermopile in designing a heat radiation detector that is particularly suitable for detecting the radiant heat from the sun. It is so arranged that the heat radiation warms a set of junctions while a second set is effectively shielded from the direct incidence of the radiation. The resulting thermoelectric e.m.f is accurately measured on a modified form of the potentiometer.

The System Design

An array of 100 hot junctions is mounted on a wooden board measuring 50cm x50cm. Another array of 100 cold junctions is similarly mounted on a separate wooden board measuring 46 cm x 46cm. Each junction which is a meeting point of a piece of wire is about 12cm. The arrangement is such that copper and constantan alternate to form a long series configuration i.e. a thermopile.

The wooden board containing the hot junctions is blackened and placed inside a metal cabinet (fig. a). A plain glass 3mm thick is used to cover the top of the metal casing. The board containing the cold junctions is painted white and placed beneath the metal cabinet so that cold junctions are shielded from the direct incidence of the heat radiation falling on the plain glass cover. A muslin is attached to each cold junction in such a way that itȡs free end extends into a semi-permeable clay pot filled with cold water. This locally made clay pot is placed beneath the array of cold junctions.

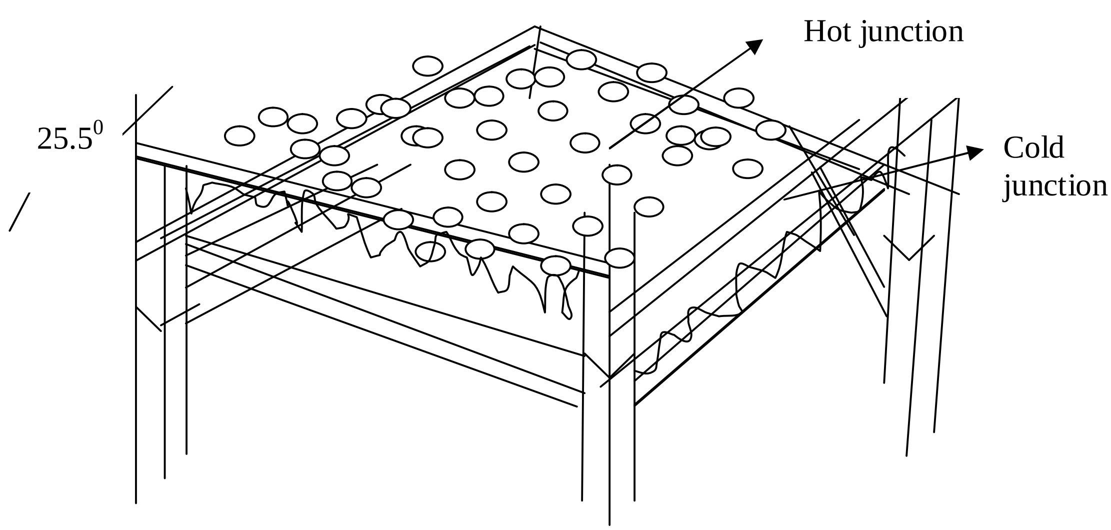

Fig (a): Pictorial Representation of the Detector.

The muslins are partially immersed in the cold water so that the water rises (capillarity) through them unto the cold junctions , thereby producing an excellent cooling effect as evaporation takes place.

The entire set-up is mounted on metal s which act as a base for supporting the arrangement and tilting the flat plate collector through the desired angle (25.5^0 for Agbor). An insulating material is stuffed into the space between the boards containing the array of hot and and cold junctions to minimize heat conduction across the space. The thermoelectric e.m.f is tapped across the first and the last pieces of wire.

Measurement of the Thermoelectric E.M.F

In general, the thermoelectric e.m.f of a thermocouple is given by,

$E = aT + bT^2$ é é é é é é é é é ..(1)

where a, b are constants and T^oC is the temperature of the hot junction when the temperature of the cold junction is 0^oC. For copper ï constantan combination a = 41.00 and b = 0.04. Also, by Stefanõs law of radiation, the total radiant energy, falling on a square meter per second is given by,

$P = \varepsilon\sigma T^4$ é é é é é é é é (2) where $\sigma = (5.7x10^{-8}\ Wm^{-2}K^{-4})$ is Stefanõs constant, T is the corresponding absolute temperature and ε the emissivity of the material.

In this study, however, a modified version of the potentiomenter (fig b.) is used to measure the thermoelectric e.m.f as accurately as possible. Here, the thermoelectric e.m,f E is applied via a sensitive galvanometer G across a standard shunt of 1.50Ω .

A current of about 5mA is passed through R and measured on the milliammeter M. Both current are in opposition. The rheostat Rh is then used to vary the current until a balance point is achieved i.e until G shows no deflection.

At balance, the potential difference across R is then equal and opposite to the thermoelectric e.m.f, so that,

$E = I R$

Thus $E = 1.5 I$é é é é é é é (3)

Since, $R = 1.5\Omega$

where I is the reading of the millimeter at balance.

This modified potentiometer eliminates most of the usual sources of error associated with the common type of potentiometer; it eliminates the error due to the non-uniformity of the slide ï wire and the uncertainty in measuring the balance length of the slide wire.

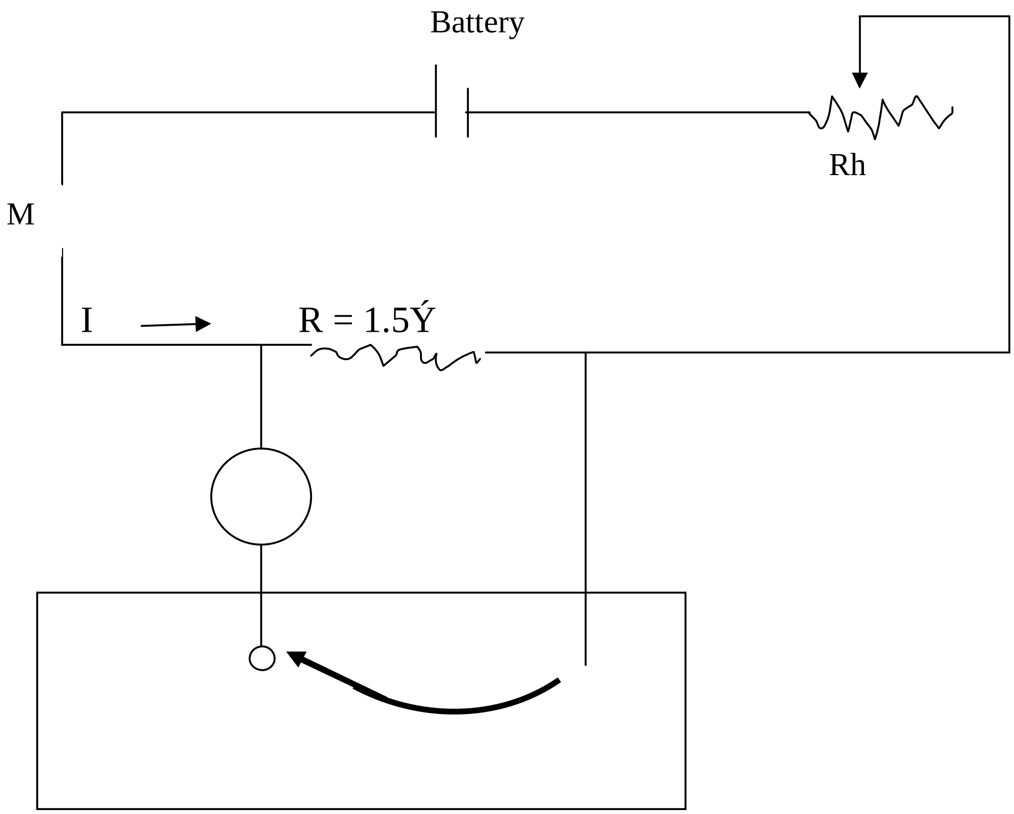

Fig (B): Modified Potentiometer Arrangement for measuring thermoelectric e.m.f of Detector

The System Performance

Since the radiant heat is essentially the only quantity that is responsible for the thermoelectric e.m.f, it follows that the thermoelectric e.m.f, is conversely a measure of the heat radiation ï within the framework of equations (1) and (3)

The following are some representative data showing the overall performance of the device.

Rang of temperatures for the hot junctions: 29^0C ï 81^0C
Range of temperatures for the cold junctions: 24.0^0C ï 28.0^0C (with muslin).
Range of temperatures for the cold junctions: 29.40^0C ï 42.0^0C (without muslin).
Range of thermoelectric e.m.f generated: 0 ï 14.8mV (with muslin).
Range of thermoelectric e.m.f generated: 0 ï 6mV (without muslin).
Range of thermoelectric e.m.f generated during the night (due to back radiation)
0 ï 2mV (without muslin).
Range of thermoelectric e.m.f generated at night 0.5 ï 1.8mV (without muslin).
Range of the total energy arriving at a square meter: 0 ï 1.10Kwm$^{ï 2}$

Above results represent a summary of the readings taken between January and April 2010.

The energy per square meter, from sun was measured with the metrosol while the thermal e.m.f was measured with detector.

Calibration of the Detector

The variations, with local time, of the thermoelectric e.m.f (radiant heat variation) and the incident intensity of the total radiation exhibit certain features with striking regularity.

Since transparent objects absorb a finite percentage (depending on the nature of the material)of the infra-red radiation, and since all the energy from the sun are not in the form of radiant heat, it is not convenient to calibrate the heat detector directly using the metrosol. However, a comparison of the general features of the curve of thermoelectric e.m.f versus local time with those of the curve of incident intensity versus the local time would serve to bring out the weak and the strong points of the radiant heat detector.

The P ï t curve rise gradually from zero up to a sharp, well defined maximum (fig. c) On the other hand, the E ï t curve rises gradually from zero up to a flattened plateau with the clearly defined turning point (fig. d). Both the P ï t and E ï t curves gradually decay to zero thereafter.

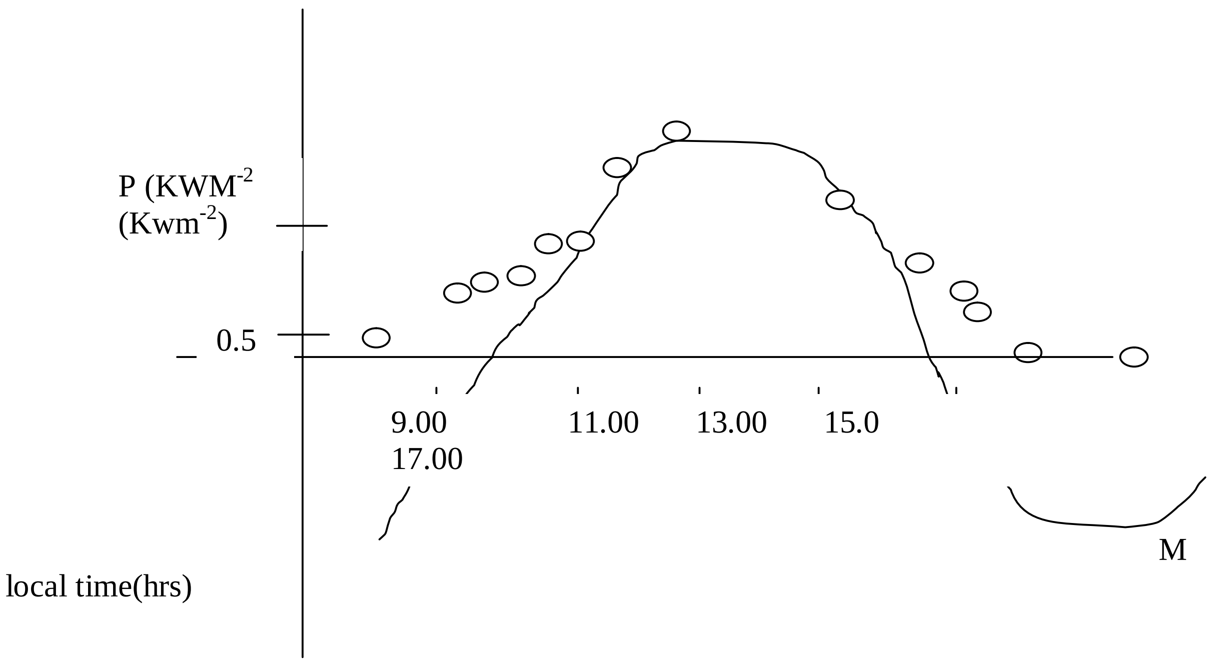

Fig (c) : Insolation versus local time for a typical day.

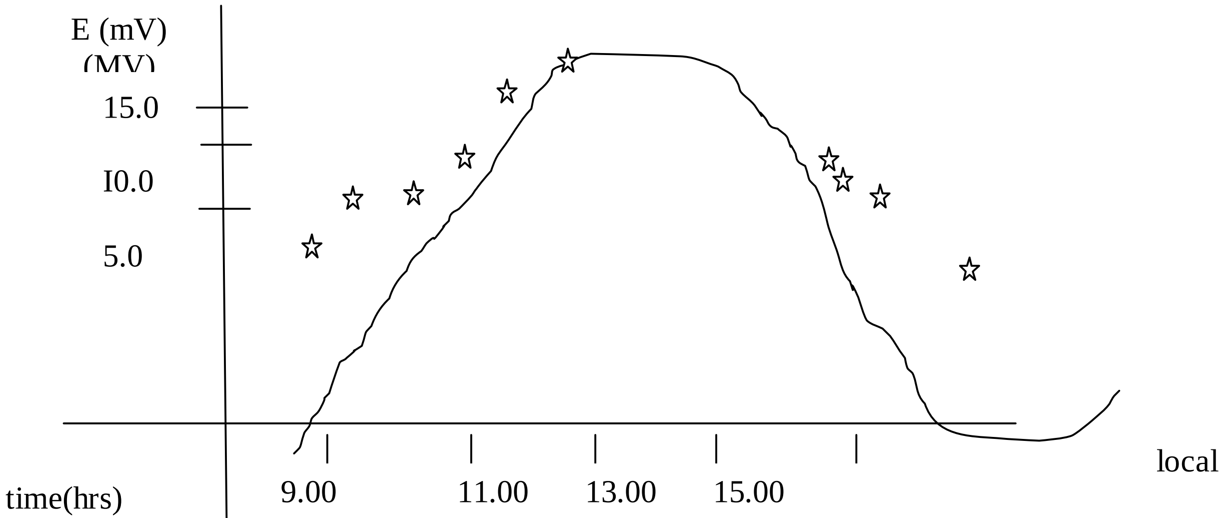

Fig (d): thermoelectric E.M.F verus local time for the entire day

Characteristically, the plateau (flat top) of E ï t curve occurs between about 11.30am and 2.45pm. Thus, the instrument is least sensitive around the mid-afternoon. It achieves great sensitivity towards the late hours of the evening (3.00pm ï 6.30pm). It is also very sensitive in the early hours of the morning (6.15am ï 1130am). The overall sensitivity is increased by maintaining the cold junction at very low temperatures ï especially when they are kept constant at $0^{o}C$.

It is also found that the sensitive of the instrument in the afternoon becomes greatly improved when the plain glass cover is removed. This is probably due to the Green House effect of the glass cover.

It is most convenient to calibrate the radiant heat detector directly using another detector of heat radiation. The closest approximation was achieved when the detector was used without the glass is cover.

On the other hand, when the glass cover is removed, the thermoelectric e.m.f. generated per unit isolation per unit area becomes significantly reduced thereby rendering the instrument more sluggish; the warm-up time is considerably increased. The variation of E and P, with and without the plain glass cover, are presented in (fig, e)

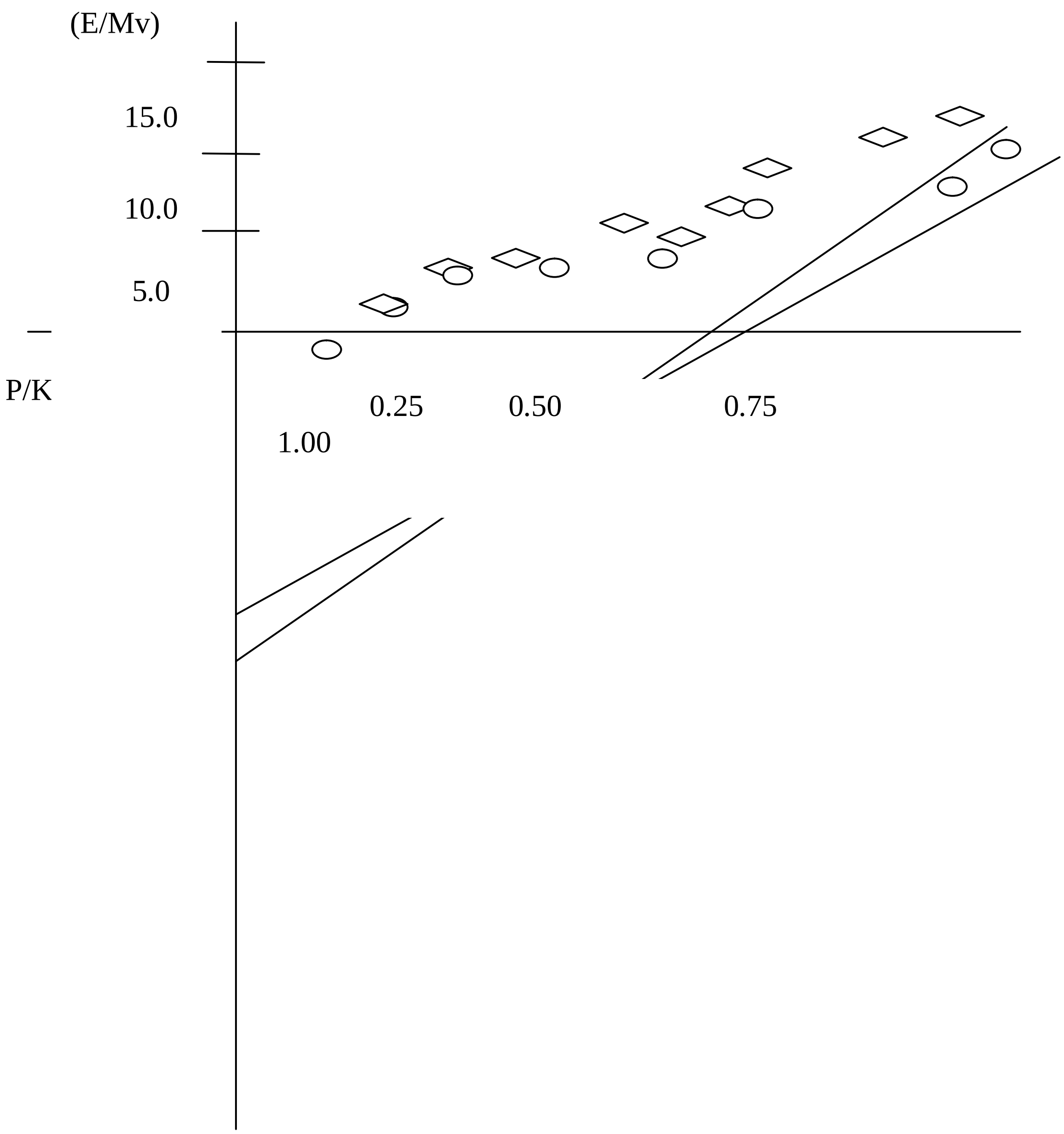

Fig (e): variation of radiant energy detected with instrument (with and without plain glass cover).
- ◇ - ◇ = calibration curve with glass cover
- O - O = calibration curve without cover.

Conclusion

A radiant heat detector is designed, constructed and tested. The device detects both the infra-red radiation and the radiant heat characteristic of the visible spectrum.

When carrying out investigations on the visible spectrum, ordinary glass cover is used to filter off a significant percentage of the infra-red radiation.

When carrying out investigations, on the infra-red radiation, rock-salt cover, which does not absorb infra-red radiation, is used to replace the ordinary glass cover (a thin film of common salt serves adequately).

The instrument is least sensitive around the mid-day but the sensitivity improves considerable during the later (and earlier) hour of the day. The sensitivity is also improved by lowing and stabilizing the temperature of the cold junctions.

The instrument is quite cheap and reliable. It is particularly suitable for detecting radiant heat from outer space.

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