Radiation Shields for Air Temperature Thermometers[1]

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1. Introduction

Both aspirated and naturally ventilated thermometers are commonly shielded in order to minimize errors resulting from radiation exchange. A good shield should be at a temperature close to that of the air; however, solar as well as thermal radiation exchange at the shield can cause significant error. Direct and reflected solar radiation causes the largest errors because thermal radiation sources usually are at a temperature not very different from air temperature. An ideal shield should totally reflect solar radiation; however, all reflective coatings available absorb some solar energy which must be dissipated. The heat dissipation from the shield is governed not only by the degree of ventilation but also by the thermal emissivity (absorptivity) of the surface. The relation of solar radiation absorptivity to thermal absorptivity in collecting and dissipating heat is frequently disregarded in the construction of thermometer shields.

The purpose of this note is to illustrate the behavior of a number of shield coatings with selective absorption characteristics for solar and thermal radiation. The effect of weathering on the coating characteristics also is illustrated. Chrome plating, polished aluminum, and white paint are among the shield surfaces commonly used and are included here.

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The heat balance of an opaque shield surface is

$$a_sR_s+a_tR_t=a_t\sigma T^4+L, \qquad (1)$$

where R_s and R_t are the flux densities of solar and thermal radiation incident to the surface, a_s and a_t are the respective absorptivities, σT^4 is the black body radiant heat flux density for a temperature T(°K) at the shield surface, and L is the convective heat loss per unit area. Conduction through supports is neglected in this discussion. The convective transfer is $L=h(T-Ta)$ where Ta is the air temperature and h is the transport coefficient which depends upon the shield configuration and the air circulation. When L is large, it is an important factor in keeping shields near air temperature. However, our concern is with the effect of a_s and a_t in Eq. (1) on the heat balance of the shield, for a fixed h. Eq. (1) shows that shield coatings with selective absorptivities can be chosen to minimize $(T-Ta)$ for any arbitrarily given transport coefficient, h.

The properties of selective coatings have found their main applications for solar energy collectors (Gier and Dunkle, 1955; Tabor, 1955) and for the temperature control of satellites (Alexander, 1964; Thaler *et al.*, 1964). Efficient solar energy collectors have high values of a_s/a_t. A thermometer shield for solar radiation should be as inefficient a solar collector as possible. When $R_s>0$ and $(a_sR_s+a_tR_t)>a_t\sigma T^4$, T decreases as a_s/a_t decreases regardless of L. It should be noted that this condition represents the general daytime situation for a surface facing the sky. The same condition obtains for a surface facing the soil because the net thermal radiation exchange with the heated soil is usually less than the solar radiation reflected by the soil. On the other hand, this choice is objectionable when R_s approaches zero and $(a_sR_s+a_tR_t)<a_t\sigma T^4$, T falls below T_a and this temperature drop increases as a_t increases. It will be shown, however, that this effect is less critical than the one observed with low a_t in the presence of solar radiation.

2. Experimental procedure

The effect of the radiation characteristics of several types of coatings on the surface temperature has been tested. Table 1 gives the list of coatings used and the manufacturer's number. The coatings, except for chrome-plating were applied on aluminum squares, 15×15 cm in area and 0.6 mm thick, with thermocouples soldered at the center of the uncoated side. The white paints were brushed directly on the clean surface. The clear finishes were brushed or sprayed on aluminum foil previously cemented to the aluminum squares. Chrome plating was on a copper square of the same dimensions. In order to reduce L and emphasize the radiation characteristics, the surfaces were mounted on a polyurethane foam slab and covered by a double layer of polyethylene films in an arrangement similar to that described by Tanner *et al.* (1960) for the economical net radiometer. Although this mounting in no case represents the real conditions encountered with an air thermometer shield, it has been used because it increases the temperature differences between surfaces, and the mounting allows a more accurate computation of a_s and a_t from the measurements.

With this exposure, L is determined by the thermal conductivity of air and polyurethane foam, and is small. With small L, the temperature "excess" $(T-T_a)$, of the surface is increased and the selective behavior of the coating is emphasized. The heat balance equation is somewhat more complicated than (1) to account for the properties of the polyethylene as indicated by Tanner *et al.* (1960). The equation for the polyethylene-covered surface has the same general form as (1), and allows the computation of a_s and a_i, from the surface temperature provided R_s and R_t are known. R_s and R_t may be obtained if two reference surfaces having different absorptivities, with known values, are included in the mounting and have their surface temperature measured. A glass plate painted on the rear surface with black paint and a rear surfaced silver mirror were used here as reference surfaces. Both a_s and a_t have been determined previously on these surfaces by the National Bureau of Standards.

Measurements of the coatings were made on perfectly clear days. The temperatures of the surfaces exposed nearly normal to sun rays were continuously recorded. The equilibrium temperature values were used for the computation of a_s and a_i. Freshly applied coatings were measured on 17 April 1964. The radiation incident to the surfaces and air temperature were $R_s=1100$ watts m^{-2}, $R_t=350$ watts m^{-2}, $T_a=15.3$C when measurements were made. The same coatings were measured on 7 August 1964 after a three-month period of weathering. The radiation and air temperature were $R_s=960$ watts m^{-2}, $R_t=480$ watts m^{-2}, $T_a=29.6$C. During weathering, the polyethylene films were removed and the surfaces were faced to the south at a 45° inclination. Duplicates of the reference surfaces and of two other surfaces were stored and were unweathered for the second test. Table 1 reports the temperature measurements from which the values of a_s and a_t were computed, accounting for the presence of the polyethylene films.

3. Results and discussion

The temperature excess $(T-T_a)$, is least with the rear-surfaced mirror, and followed by aluminized Mylar, the white paints, the foil with clear finishes, and the white porcelain. The aluminized Mylar and surfaces with clear finish on the aluminum foil are similar to the rear-surfaced mirror in that the solar radiation is reflected by the metal substrate whereas the thermal absorptivity (emissivity) is governed by the finish coat. The temperature excess of plain aluminum foil, chrome plating, and the black paint are substantially larger than of other surfaces. Though both aluminum and chrome-plating have low absorptivity for solar radiation, that for thermal radiation is much lower still.

The thermal absorptivity for the non-metallic coatings are all close to 0.91 as determined earlier for the glass. This experiment was not sensitive enough to find differences between them. This value agrees well with data reported by Dunkle (1963) for the Cat-a-lac white paint.

Weathering generally increased the solar absorptivity of the white paints tested and at the same time reduced the differences between them. Deterioration of the clear finishes was less apparent except for the latex and epoxy coatings. The aluminized Mylar was very stable and its temperature excess remained the lowest among the tested surfaces except for the rear-surfaced mirror. It is of interest that the white porcelain kept in storage changed as much as the weathered porcelain surface. We have no explanation for this.

Though aluminum and chrome-plating withstand weathering, they are not good for solar radiation shields. Gold, which was not tested, also is very stable and is used in radiation shields (e.g., Cramer, *et al.*, 1957). In order to compare gold with the tested surfaces $(T-T_a)$ has been computed for the conditions of the two sets of measurements, using $a_s=0.21$ (smallest value found in literature) and $a_t=0.08$ (Gubareff *et al.*, 1960). The computed $(T-T_a)$ were 86C and 78C for the first and second set of measurements, respectively. Thus gold and chrome-plating are not much better than black paint for solar radiation shields which exchange heat only at one surface.

The effect of thermal radiation alone was tested by a set of measurements made at night (10 August 1964, $R_t=367$ watts meter^{-2}, $T_a=22.4$C). The temperature drops (T_a-T), for all the surfaces with high a_t were around 8C, and only 3.6C for the low a_t surfaces. Thus at nighttime, a small a_t is desirable; however the nighttime (T_a-T) associated with large a_t is much less than the daytime $(T-T_a)$ for small values of a_t illustrated in Table 1.

The measurements indicate that selective coatings with a small a_s/a_t ratio are best for solar radiation shields, particularly when they are resistant to weathering. Aluminized Mylar, white paint, and clear coatings on polished aluminum foil are preferred in that order. The metal surfaces are best suited for shielding from thermal radiation and should not be used for solar radiation shields.

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TABLE 1. Radiative characteristics and temperature excesses for coatings normally exposed to sun rays before (17 April 1964) and after weathering (7 August 1964).

Surface	Company type	17 April 1964		7 August 1964		
		$T-T_a$ (deg C)	a_s	$T-T_a$ (deg C)	a_s	a_t
Glass, black rear-surfaced*	—	101.4	0.95	86.9	0.94	0.91
Glass, silver rear-surfaced mirror*	—	7.6	0.07	9.9	0.07	0.91
White porcelain, unleaded frit, 19% TiO_2*	—	34.8	0.25	34.9	0.29	0.91
White, flat*	Finch 463–1–500	28.2	0.20	26.6	0.21	0.91
Glass, black rear-surfaced	—	100.9	0.94	85.9	0.93	0.91
Glass, silver rear-surfaced mirror	—	7.4	0.07	9.9	0.07	0.91
Chrome plating	—	92.1	0.28	78.3	0.28	0.12
Aluminum foil	—	44.7	0.12	42.0	0.13	0.05
Aluminized Mylar	—	25.6	0.19	27.8	0.22	0.91
White porcelain, unleaded frit, 19% TiO_2	—	33.2	0.24	33.8	0.28	0.91
Alkyd satin white	Mautz E725	30.0	0.22	31.5	0.26	0.91
Epoxide white enamel	Mautz 7810S+7722S	29.3	0.21	31.5	0.26	0.91
White, flat	Finch, 463–1–500	29.1	0.21	30.6	0.25	0.91
Alkyd gloss white	Mautz 725	25.3	0.18	29.9	0.24	0.91
Clear acrylic, spray can†	Mautz 835	38.9	0.28	36.8	0.31	0.91
Satin finish, spray can†	Mautz 834	38.2	0.28	37.2	0.31	0.91
Polyurethane isocyanate†	Mautz V203	34.6	0.25	32.8	0.27	0.91
Air dry epoxy†	Mautz V100	33.7	0.24	36.4	0.30	0.91
Clear oil alkyd†	Mautz V103	33.4	0.24	31.5	0.26	0.91
Polyurethane isocyanate†	Mautz V200	33.4	0.24	33.8	0.28	0.91
Clear acrylic latex†	Mautz AC34	33.4	0.24	44.5	0.39	0.91
Acryloid B7†	Cadillac Plastics	33.2	0.24	32.3	0.26	0.91
Modified polyurethane epoxy†	A.D.M. 505 (Mautz)	30.4	0.22	33.0	0.27	0.91

* Nonweathered duplicates.
† Clear finish on aluminum foil.

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