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SOLAR REFLECTANCE, TRANSMITTANCE AND ABSORPTANCE OF COMMON MATERIALS

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ABSTRACT

The solar reflectance, transmittance and absorptance of common materials used for solar collector fabrication have been compiled for easy reference. The data are derived from solar weighted averaging techniques and can be used for initial calculations of collector performance.

INTRODUCTION

To calculate the efficiency of a solar collection system, one must know the appropriate solar and infrared spectral properties for the optical components. For flat plate systems one must have the optical properties of the glazing and absorber materials in both the solar (0.3 μm to 2 μm) and thermal infrared (2 μm to 30 μm) spectra to account for solar reflectance losses and the redistribution of thermal energy respectively. For concentrating systems using a transmitting element such as a fresnel lens or for air inflated point and line focus collector systems fabricated from thin polymer films the solar transmittance of the material becomes most important. For reflecting concentrators, it is necessary to know the solar reflectance of the mirror of interest. This paper compiles an up-to-date listing of the optical properties of a wide variety of common materials used to fabricate solar collectors. The data results from measurements on average pieces of material delivered through the normal commercial supply system and thus should represent the material performance which a solar collector manufacturer might expect. Caution should be used if the materials of interest for a particular collector system have been specially fabricated or compounded to provide "better" optical properties.

The data presented in this paper should be sufficiently accurate to provide a reasonable calculation of the expected performance of a specific solar system. In addition to providing performance data, the data is organized into tables which give performance values and some indication of the stability of the materials as a function of time of solar radiation exposure. These are qualitative estimates based on our accumulative exposure experience and are not derived in a scientific manner. The numbers are guidelines to materials selection and should not be used to attempt to predict system lifetimes,

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RESULTS AND DISCUSSION

The properties of a number of polymeric materials including transmittance data are shown in Table 1 [1-5] and were compiled to allow the performance of flat plate solar collectors to be calculated. The solar and infrared transmittance can be used to develop a thermal balance equation for a collector operating at a given solar flux input and fluid inlet and outlet operating temperatures. In addition, knowledge of the refractive index also allows the calculation of how these materials would perform as concentrating elements such as fresnel or common lenses. Sample calculations and detailed use of this data is illustrated in reference [1]. The cost of transmitting materials varies widely and must also be considered in the materials selection process.

One should remember that in calculating the daily performance of a collector the reflectance loss changes as a function of the angle and the refractive index. It should also be noted that these properties are taken for materials with a smooth surface and that an abraded or otherwise disturbed surface can drastically alter the interface reflection loss and thereby effect the transmittance of the material. For transmitting concentrator applications, the surface smoothness and contour are extremely important and must be taken into account when trying to calculate the concentration ratio and collector performance.

Reflecting materials used to augment flat plate collectors or as reflecting elements in concentrating collectors must have both high absolute reflectance in the solar spectrum and high specularity. Specularity is the ability to reflect a ray without significantly broadening that ray. The poorer the specularity of the mirror, the larger the receiver must be in order to capture the sun's reflected energy due to the broadening of the solar image caused by the mirror itself. The sun's image can be further degraded by the attachment technique used to afix a thin film mirror to a supporting substrate, i.e., a very non-uniform adhesive layer can introduce waviness and roughness to the reflector surface. Table 2 provides reflectance data for mirror materials in low, intermediate and high concentration applications. Based on the spatial scattering profile measured for real mirror surfaces an expression for the reflectance [$R(\Delta\theta)$] is derived in reference [6] as a function of the angle ($\Delta\theta$) from the specular direction. In general the specular profile is found to be comprised of the sum of two normal distributions. The angle subtended by the receiver (τ) in a solar concentrator determines the effective reflectance for that particular system and is given by

$$(1) \quad \tau = 2 \tan^{-1} (D/2x)$$

where D is the receiver diameter and x the distance from the reflector to the receiver. The effective reflectance R' is given by

$$(2) \quad R'(\tau) = \int_{-\tau/2}^{+\tau/2} R(\Delta\theta)\, d(\Delta\theta)$$

and Table 2 compiles estimated R' values for apertures of 4, 10, and 18 milliradians. Most single axis concentrating systems have subtended angles greater than 18 milliradians. It is only when the mirror to receiver distance gets quite large as in heliostat or extremely large line focus arrays that numbers less than 4 milliradians are found. Table 2 will allow the system designer to approximate the new reflectance of a mirror. Washing should bring the mirror back to close to its original reflectivity but may not bring it back to the full value if surface abrasion has been caused by the cleaning procedure. This degradation is especially a problem for plastics and metals. Again, the lifetimes of the materials have been qualitatively evaluated and cost should be determined prior to a materials selection.

The ability of a material to absorb sunlight is quite important, and the solar absorptance of a number of commonly available materials is given in Table 3. Some of these materials have--in addition to a high solar absorptance--low thermal emittance and therefore are called selective absorbers. The benefit of a selective absorber is that it will suppress reradiation of thermal energy from the receiver surface. A detailed description of absorber materials applications and the nature of selective absorber materials can be found in reference [7]. The major tradeoff between selective and non-selective materials is cost versus performance. Non-selective materials tend to cost much less than the selective materials; however, selective absorbers are frequently chosen for flat plate and concentrator applications because of the improved performance which can be obtained. In flat plate solar systems a rule of thumb is that a collector with a single glazed selective absorbing surface is roughly equivalent to a collector with a double glazed non-selective absorbing surface collector. The increased cost of the absorber surface may be offset by the elimination of one glazing layer. Selective materials are commonly applied by electrodeposition; non-selective materials are applied by painting; both can be applied to large areas. The thermal stability of the available materials is qualitatively given, but it is important to check the absorber material of interest in the particular application before making any claims as to actual system life.

SUMMARY AND CONCLUSIONS

The data presented in this paper are indicative of the range of optical properties of materials which are available to solar collector designers at this time. A significant amount of research is taking place to quantify the stability of the available materials and to identify new or improved materials which could be added to these lists. The tables give nominal numbers for the commercially produced materials. The service life at these performance levels will depend on proper cleaning and maintenance. In addition, batch-to-batch variations in materials could also give small variations in these optical properties. If there is uncertainty regarding a value, the appropriate property of the actual material used in the collector should be measured to provide the most accurate system performance calculation. These numbers are offered as a preliminary guide to the selection and use of materials in solar collector designs.

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TABLE I

THERMAL AND OPTICAL PROPERTIES OF COVER PLATE MATERIALS [1]

Material	Index of Refraction	Normal Incident Short-wave Transmittance ($\lambda=0.4-2.5\mu$)	Normal Incident Long-wave Transmittance ($\lambda=2.5-40\mu$)	Thickness* (m)	Density (kg/m^3)	Specific Heat (J/^{0}K-kg)	Thermal** Capicity (W-hr/^{0}K-m^2)	References
Glass	1.518	0.840	0.020	3.175×10^{-3}	2.489×10^{3}	0.754×10^{3}	1.659	(2)
Fiberglass Reinforced Polyester (Sunlite)	1.540	0.870	0.076	6.350×10^{-4}	1.399×10^{3}	1.465×10^{3}	0.361	(2)
Acrylic (Plexiglas)	1.490	0.900	0.020	3.175×10^{-3}	1.189×10^{3}	1.465×10^{3}	1.534	(2)
Polycarbonate (Lexan)	1.586	0.840	0.020	3.175×10^{-3}	1.199×10^{3}	1.193×10^{3}	1.260	(2)
Polytetrafluoroethylene (Teflon)	1.343	0.960	0.256	5.080×10^{-5}	2.148×10^{3}	1.172×10^{3}	0.036	(2,3)
Polyvinyl Fluoride (Tedlar)	1.460	0.920	0.207	1.016×10^{-4}	1.379×10^{3}	1.256×10^{3}	0.049	(2)
Polyester (Mylar)	1.640	0.870	0.178	1.270×10^{-4}	1.394×10^{3}	1.046×10^{3}	0.051	(2)
Polyvinylidene Fluoride (Kynar)	1.413	0.930	0.230	1.016×10^{-4}	1.770×10^{3}	1.256×10^{3}	0.063	(4), Fig.2
Polyethylene (Marlex)	1.500	0.920	0.810	1.016×10^{-4}	0.910×10^{3}	2.302×10^{3}	0.059	(3,5)Fig.2

* These values correspond to the thickness associated with the stated transmittances. They were used in the simulations to compute thermal capacity and are representative of commercially available film thicknesses.

**Thermal capacity = (Thickness) (Density) (Specific heat)

TABLE 2

SPECULAR REFLECTANCE PROPERTIES OF SEVERAL MIRROR MATERIALS[6]

Material	Supplier	Estimates of Solar Weighted Reflectance[b] R'(τ) τ=4mr	10mr	18mr	$R_s(2\pi)$
I. Second-Surface Glass					
(a) Laminated Float Glass - 2.7 mm thick - silvered	Carolina Mirror Co.	0.83	0.83	0.83	0.83
(b) Laminated Low-Iron Sheet Glass - 3.35 mm thick - silvered	Gardner Mirror Co.	0.90	0.90	0.90	0.90
(c) Corning Silvered Microsheet Co.-0.114 mm thick - Mounted on optically flat plate	Corning Glass	0.76	0.87	0.92	0.95
(d) Corning 0317 Glass - 1.5 mm thick - Evaporated silver	Corning Glass	0.95	0.95	0.95	0.95
II. Metallized Plastic Films					
(a) 3M Scotchcal 5400 Laminated to backing sheet	3M Company	0.60	0.84	0.85	0.85
(b) 3M FEK-163 Laminated to backing sheet	3M Company	0.83	0.85	0.85	0.85
(c) Aluminized 2 mil FEP Teflon (G405600) Laminated to backing sheet	Sheldahl	0.70	0.81	0.82	0.87
(d) Silvered 2 mil FEP Teflon (G400300) Mounted on Optically Flat Plate	Sheldahl[a]	0.73	0.82	0.90	0.96
(e) Silvered 5 mil FEP Teflon (G401500) Mounted on Optically Flat Plate	Sheldahl[a]	0.77	0.83	0.89	0.95
(f) Front Surface Aluminized Mylar (200XM648A) stretched membrane	Boeing	0.88	0.88	0.88	0.88
III. Polished, Bulk Aluminum					
(a) Alzak Type I Specular	Alcoa				0.85
Perpendicular to rolling marks		0.61	0.68	0.76	
Parallel to rolling marks		0.68	0.76	0.83	
(b) Kinglux No. C4	Kingston Ind.				0.85
Perpendicular to rolling marks		0.67	0.71	0.75	
Parallel to rolling marks		0.69	0.71	0.75	
(c) Type 3002 High Purity Al - Buffed and Bright Anodized	Metal Fabrications, Inc.[a]	0.44	0.60	0.71	0.84

a) Experimental materials not produced in high production, so cost information is lacking.

b) Estimated from ≈500 nm specularity data ref. [6] and solar weighted total hemispherical reflectance data. Standard deviation of the estimates is about 2%.

TABLE 3

PROPERTIES OF SELECTED COMMERCIAL SOLAR ABSORBER SURFACES [7]

Material	Technique	Supplier (S)/ Developer (D)	α_s	ε_t(T)	T Stability** (^{0}C)
Black Chrome	electro-deposited	Many	0.94-0.96	0.05-0.10(100) 0.20-0.25(300)	300
Pyromark	paint	Tempil	0.95	0.85(500)	<750
S-31 (nonselective)	paint	Rockwell International	0.8-0.85	0.8-0.85	>550
SOLARTEX	electro-deposited	Dornier (W. Germany)	0.93-0.96	0.14-0.18(310)	700
SOLAROX (proprietary)	"	"	0.92	0.20	200
Black Epoxy	paint	Amicon Corp.	NA	NA	NA
436-3-8	"	Bostik (U.S.M. Corp.)	0.90	0.92	NA
Enersorb	"	Desoto	0.96	0.92	NA
7729	"	C. H. Hare	0.96	0.90-0.92	NA
R-412	"	Rusto-leum Co.	0.95	0.87	NA
5779	"	"	0.95	0.90	NA
Nextel (nonselective)	"	3-M	0.97-0.98	>0.90	150
NOVAMET 150 (proprietary)	"	Ergenics	0.96	0.84	800 (1 hr)
MAXORB	(proprietary)	Ergenics	0.97(±.01)	0.10(±.03)	150(20 wks) <400(1 hr)
Tabor Black (NiS/ZnS)	electrodeposited + overcoat	Miromit	0.91	0.14	-