Comparative evaluation of the infrared transmission of polymer films

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Abstract

The total infrared (IR) transmission of polymer films is a very important property in engineering, which determines their suitability for a specific application at a given temperature level. Aiming to investigate the total IR transmission of various polymer material films of a particular thickness, an analysis is developed for the comparative evaluation of this very important physical property. Excitation of the radical bonds in randomly oriented, long chain polymer molecules by absorption of IR radiation usually causes a large number of sharp resonances at various wavelengths and is responsible for the characteristic shape of the spectral transmission plot for the particular polymer material. The comparative presentation of results shows that at least as far as the accuracy of the available data is concerned, the total transmission of a polymer film is determined by the specific spectral transmission characteristics of the material and may vary remarkably as a function of the radiant source temperature. According to the derived results, polymer films made of materials like plexiglass, mylar, kapton and fiberglass appear to be remarkably less transparent than other film materials like polypropylene or, even more, polyethylene, which are remarkably transparent, almost uniformly, within the wavelength region under consideration. This certainly determines the potential of the particular films for use in a specific application like the design of solar collector glazing systems or convection suppression windscreens in radiative cooling panels.
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Keywords: Polymer film transmission; Solar collector glazings

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Nomenclature

b	film thickness (m)
I	radiation intensity (W m^{-2})
k	extinction coefficient (–)
n	refractive index (–)
$\boldsymbol{n}$	complex refractive index
Q	correction factor (–)
r	reflection loss coefficient (–)
T	temperature (°C)
x	path length (m)

Subscripts

a	air
f	film
λ	wavelength
0	at distance $x = 0$

Greeks

α	absorption coefficient (m^{-1})
θ	angle of incidence
λ	wavelength (m)
τ	transmission coefficient (–)
φ	refraction angle

1. Introduction

Glass is a non-weatherable material, almost completely opaque to the IR spectrum, and from this point of view, it is considered to be very important for window glazing and the solar collector industry as well as in architecture and greenhouses. Although it has been established as a material of undisputable qualities, certain polymer films, being almost completely opaque to the IR spectrum, appear to possess the potential to compete with glass in many aspects of contemporary glazing technology. At the same time, there are other applications where transparency to the IR spectrum is a highly desirable property. This happens, for example, in radiative cooling technology, where polymer films are being employed as convection suppressing windscreens to the radiative surfaces. In these applications, the fundamental characteristic of partial infrared transmission of polymer films is being employed for radiative heat exchange with clear night skies through the atmospheric transmittance window.

In both cases, the development of a radiative heat exchange analysis, aiming either at the heating or at the cooling performance of solar collectors or the radiative cooling panels, respectively, is based on an accurate prediction of the total infrared transmission of these materials as a function of film thickness and radiant source temperature. From this point of view, the selection of the appropriate film material for the specific application and the thermal heat balance

calculations of various systems and components incorporating currently available polymer films is based on accurate prediction of their IR transmission. Towards this aim, a method is being developed, an analysis is performed and the comparative results of calculations on the total transmission of a wide range of polymer film materials are presented for various film thicknesses.

2. The use of polymer films in contemporary thermal design

During the past decades, numerous polymer sheets and films with specific qualities to satisfy requirements for a wide number of engineering applications were developed and manufactured as glazing materials [1–3]. Polycarbonate, polyethylene and polypropylene are widely known materials, although certain other polymers like polyesters, polyamides and polymerised vinyl fluoride where employed for the manufacture of films under the corresponding trade names mylar, capton and tedlar, respectively.

Polycarbonate resins exhibit the highest impact resistance of any rigid transparent polymer material, while polycarbonate and plexiglass sheets with water-white clarity, very high visible light transmission and opacity to the IR spectrum have been frequently employed as lightweight, break resistant glass substitutes in the glazing and fenestration industry. Since plates and sheets of these materials lack the abrasion resistance of glass, numerous transparent hard coats have been developed, as well as screening agents against UV degradation, and frequently incorporated in protective coatings. Polyethylene is suitable for low cost films with physical properties depending on their average molecular weight. Flexible and tough polyethylene films are mostly employed in the building industry as water barriers under below grade floors, as temporary enclosing material and as low cost convection suppression materials in radiative cooling design, as well as a glass substitute in certain low cost greenhouse structures.

Polypropylene sheets are characterized by very good impact strength and have outstanding resistance to stress cracking. They are usually reinforced by glass fibers and mineral fillers to improve their physical characteristics.

Polyvinyl fluoride was first manufactured several decades ago as a result of the extensive fluorocarbon research program, and films of this material, known under the trade name tedlar, were gradually improved based on an extensive aging testing procedure in a large number of pilot building and solar collector glazing systems. Tedlar films are now extensively employed in the building and solar energy industry, where they are considered to be quite suitable as inner or even outer glass substitutes in solar collector glazing systems, especially where large size, lightweight, in-situ assembled design of solar collector arrays is important.

Previous investigations on the derivation of the collector loss coefficients for collector glazings involving polymer films by Hollands and Wright [4] and the performance of radiant panels with convection suppression polymer film covers by Jannot and Coulibary [5] have been based on the assumption of a fixed average estimated value of total hemispherical transmittance of polymer films over a broad wavelength range. For the purpose of their heat transfer calculations, Edwards and Rhee [6] have calculated the total Teflon film transmittance using spectral data previously reported in the literature. Although the calculation details are completely lacking, total transmittance values around 20% were reported for a 0.1 mm teflon film. Wijeysundera and Iqbal [7] investigated the effect of an upper plastic film thickness on the collector top loss coefficient.

The assumption of using a selective absorber with a step emissivity behaviour at the transmittance window of the film may strongly simplify the situation, allowing elimination of the calculation of the hemispherical normal broadband IR transmission of polymer films. An absorber of this kind with a strong step absorptivity behaviour within the narrow atmospheric transmittance window between 8 and 13 μm was employed, for example, by Catanalotti et al. [8], who for the purpose of his analysis simply assigned a fixed transmittance value for the specifically employed polyethylene film, based on the average value of three IR spectral transmittance measurements corresponding to the edge and midpoint wavelengths of the transmittance window.

Although this procedure is not strictly valid for other than strong selective absorbers, the so estimated polyethylene transmittance was also employed as a first order approach in subsequent investigations [9] involving ordinary gray absorbers, owing to the lack of more suitable data.

Willier [10] was the first who estimated the total transmittance of the earlier type 20, 0.1 mm tedlar film for a relatively narrow temperature range of blackbody source temperatures between 0 and 200 °C using spectral extinction data over the limited IR wavelength band between 2 and 16 μm. The aim of his original investigation was the performance prediction of solar collectors using tedlar films instead of glass panes as a glazing material. Although extensive details on his analysis are not available from his original manuscript, it appears that the calculations were based on graphical integration using cumulative black body radiation tables under the assumption of the Beer's exponential attenuation law.

To avoid the inconvenience of handling sharply varying spectral absorption data, an alternative simple approximate technique has been proposed by Tien et al. [11] for engineering calculations based on the derivation of band *averaged* optical constants similar to the approach adopted by subsequent investigators [12,13] for the calculation of total transmission through a liquid water layer, which also behaves as a strongly selective absorber.

3. The calculation of radiation transmission in polymer films

Fundamental electromagnetic theory predicts that since all natural materials are imperfect dielectrics, the propagation of waves within optical materials leads to an exponential attenuation, which is characterized by the so called complex refractive index, the real and imaginary parts of which are the refractive index and the extinction coefficient of the material,

$$\boldsymbol{n} = n - jk \tag{1}$$

For the mathematical description of exponential attenuation caused by absorption in the medium, a physical quantity known as the absorption coefficient is expressed in terms of k, as

$$\alpha = 4\pi k/\lambda \tag{2}$$

where λ is the radiation wavelength. Therefore, the intensity of a monochromatic radiation beam $I_0(\lambda, \theta)$ at a wavelength λ, which propagates in a partially absorbing and negligibly scattering medium in the direction defined by the angle θ, undergoes an exponential attenuation, which is proportional to its optical path length x according to Beer's law, so the intensity of the radiation beam at a path length x is,

$$I(\lambda, \theta) = I_0(\lambda, \theta) \cdot \exp[-\alpha(\lambda) \cdot x] \tag{3}$$

The spectral transmission coefficient is defined as the ratio of the transmitted to incident intensity of the radiation beam $\tau(\lambda, \theta) = I(\lambda, \theta)/I_0(\lambda, \theta)$. When the beam is incident at the surface of a polymer film, its intensity is initially attenuated by reflection at the air–polymer interface. Assuming Fresnel reflectance with a reflection coefficient r, the reflected portion of the incident radiation is $I_0 \cdot r(\theta)$, a function of the incidence angle, with the remaining radiation intensity just crossing the interface being $[1 - r(\theta)] \cdot I_0$. This beam, which propagates in the medium, will suffer a further exponential attenuation according to Beer's law. Assuming that the absorption coefficient and the radiation path length in the polymer material are $\alpha(\lambda)$ and x, respectively, the radiation intensity just before crossing the second polymer–air interface of the film will be $[1 - r(\theta)] \cdot I_0 \cdot \exp[-\alpha(\lambda) \cdot x]$, and the emerging intensity from the second interface will become $[1 - r(\theta)]^2 \cdot I_0 \cdot \exp[-\alpha(\lambda)x]$ as a result of a second internal reflection loss at the polymer–air interface. In the processes of Fresnel reflection, the incident and refraction angles are assumed to satisfy Snell's law. However, the internal reflections at the second interface are responsible for further multiple reflections and absorption of radiation, so the total transmitted intensity is calculated as the contribution of all the multiple reflection and transmission components,

$$\begin{aligned} I(\lambda, \theta) = [1 - r(\theta)]^2 \cdot I_0(\lambda, \theta) \cdot \exp[-\alpha(\lambda)x] \cdot [1 + r(\theta)^2 \cdot \exp[-2\alpha(\lambda)x] \\ + r(\theta)^4 \cdot \exp[-4\alpha(\lambda)x] + \cdots] \end{aligned} \tag{4}$$

and therefore,

$$I(\lambda, \theta) = \frac{[1 - r(\theta)]^2 \cdot I_0(\lambda, \theta)}{1 - r^2(\theta) \cdot \exp[-2\alpha(\lambda)x]} \cdot \exp[-\alpha(\lambda)x] \tag{5}$$

If the film thickness is b, the spectral transmission coefficient for the monochromatic beam is expressed as,

$$I(\lambda, \theta) = [1 - r(\theta)]^2 \cdot [1 - r^2(\theta) \cdot \exp[-2\alpha(\lambda) \cdot b/\cos\varphi(\theta)]]^{-1} \cdot I_0(\lambda, \theta) \cdot \exp[-\alpha(\lambda) \cdot b/\cos\varphi(\theta)] \tag{6}$$

where the refraction angle $\varphi(\theta)$ is

$$\varphi = \arcsin[(1/n_f) \cdot \sin\theta] \tag{7}$$

For normal incidence, Eq. (6) becomes,

$$I(\lambda, 0) = [1 - r(0)]^2 \cdot [1 - r^2(0) \cdot \exp[-2\alpha(\lambda) \cdot b]]^{-1} \cdot I_0(\lambda, 0) \cdot \exp[-\alpha(\lambda) \cdot b] \tag{8}$$

The normal incidence reflection loss coefficient $r(0)$ at the air–polymer interface is given by the expression,

$$r(0) = [(n_f - 1)^2 + k_f^2]/[(n_f + 1)^2 + k_f^2] \tag{9}$$

where n_f and k_f are the real and imaginary parts of the complex refractive index of the refractive medium. For polymer films $n_f \gg k_f$, so the previous expression reduces to,

$$r(0) = [(n_f - 1)/(n_f + 1)]^2 \tag{10}$$

which offers the required value of the normal reflection loss coefficient as a function of the polymer film refractive index. However, owing to dispersion, this index is a function of wavelength and may sometimes exhibit strong wavelength dependance and anomalous behaviour in the IR region of wavelengths. Although its measurement is usually based on Abbe refractrometry for fixed wavelength sodium D lines (ASTM standard D 542), it should preferably be known at the whole IR band of interest. Unfortunately, such wide wavelength band data are very scarce for the materials of interest, and for the calculation of $r(0)$, one has to rely on existing literature data as typically shown in Table 1 corresponding to values of n_f from various literature sources. Although several may be based on D542 procedures, it is interesting to note from Table 1, that they are spread over a relatively narrow range around an average estimated value of 1.5. This value leads to an estimated normal reflection loss coefficient around 0.04, something which, for practical film thicknesses, leads to,

$$r(0)^2 \cdot \exp[-2\alpha(\lambda) \cdot b] \ll 1 \tag{11}$$

and therefore, Eq. (8) becomes,

$$I(\lambda, 0) = [1 - r(0)]^2 \cdot I_0(\lambda, 0) \cdot \exp[-\alpha(\lambda) \cdot b] \tag{12}$$

Lodenquai [14] suggested that the transmission expression (6) should be corrected by the introduction of an extra multiplicative factor Q_f arising from the complex nature of the refractive index of the partially conducting polymer film and given by the expression,

$$Q_f = [\text{re}(\boldsymbol{n}_a/\boldsymbol{n}_f) \cdot \text{re}(\boldsymbol{n}_f/\boldsymbol{n}_a)]^{-1} \tag{13}$$

where $\boldsymbol{n}_a$ and $\boldsymbol{n}_f$ are the complex refractive indices of air and polymer film, respectively. Since air can clearly be considered a perfect dielectric material, its complex refractive index is $\boldsymbol{n}_a = 1$, while the complex refractive index of the polymer film material can be written in terms of its real and imaginary parts, corresponding to its refractive index and extinction coefficient, respectively, $\boldsymbol{n}_f = n_f - jk_f$.

Therefore,

$$\text{re}(\boldsymbol{n}_f/\boldsymbol{n}_a) = n_f \tag{14}$$

Table 1
Refractive index and normal incidence reflection loss coefficient of various polymer films

Material	Refractive index n_f	Source	$r(0)$
Plexiglass	1.49	1.49 [1,15,16]	0.0387
Fiberglass	1.54	1.54 [15,16]	0.0451
Polycarbonate	1.586	1.586 [1,3,15,16]	0.0513
		1.6 [17]	
Polyethylene	1.5	1.5 [17,18]	0.0400
		1.51–1.54 [1]	
Polypropylene	1.5	1.5 [1]	0.0400
Tedlar	1.46	1.46 [15,16] 1.45 [18]	0.0349
Mylar	1.64	1.64 [16–18]	0.0587
		1.62 [15]	
Kapton	1.816	1.816 [17]	0.0839
Vinyl	1.5	–	0.0400

and

$$\mathrm{re}(\boldsymbol{n}_a/\boldsymbol{n}_f) = n_f/(n_f^2 + k_f^2) \tag{15}$$

Combining Eqs. (14) and (15) with Eq. (13), it is possible to obtain the numerical value of Q_f, which is,

$$Q_f = 1 + (k_f/n_f)^2 \tag{16}$$

Assuming that $\alpha_f(\lambda)$ is the film spectral absorption coefficient, combination of Eqs. (2) and (16) yields,

$$Q_f = 1 + [\lambda \cdot \alpha_f(\lambda)/4\pi \cdot n_f]^2 \tag{17}$$

The numerical value of Q_f from Eq. (17) can be evaluated by using typical values of the derived spectral absorption coefficient data $\alpha_f(\lambda)$ for a corresponding wavelength λ and an average value for the refractive index of polymers around 1.5. It was found that the estimated numerical value of Q_f is very close to unity, so the assumption of $Q_f = 1$ leads to negligible errors, which are within the graphical compilation uncertainty and measurement error order of magnitude.

Therefore, it is possible to use Eq. (12) for calculation of the normally transmitted energy through a polymer film of thickness d at a wavelength λ. As soon as the spectral absorption coefficient is known over a broad range of wavelengths from $\lambda_{\min}$ to $\lambda_{\max}$, it is possible to calculate the total transmitted energy by the expression,

$$I_b = [1 - r(0)]^2 \cdot \int_{\lambda_{\min}}^{\lambda_{\max}} I_0(\lambda, 0) \cdot \exp[-\alpha(\lambda) \cdot b] \, d\lambda \tag{18}$$

Since the total transmission through the polymer film of thickness d is defined as the ratio,

$$\tau_b = I_b/I_0 \tag{19}$$

where I_0 the total normally incident energy at the film surface, the total transmission is calculated by the expression,

$$\tau_b = [1 - r(0)]^2 \cdot \int_{\lambda_{\min}}^{\lambda_{\max}} I_0(\lambda, 0) \cdot \exp[-\alpha(\lambda) \cdot b] \, d\lambda \bigg/ \int_{\lambda_{\min}}^{\lambda_{\max}} I_0(\lambda, 0) \, d\lambda \tag{20}$$

where the denominator of Eq. (20) represents the total incident energy, I_0.

4. The selection of optical properties from literature sources

A literature survey indicates that references on detailed spectral absorption data for a wide range of polymer materials from bibliographical sources are scarce, and therefore, one has to rely on the few scattered transmission measurements, which were derived for specific materials and were reported from independent investigators. Spectral absorption coefficient data can readily be derived when spectral absorption measurements for two fixed film thicknesses b_1 and b_2 of the same material are available. The spectral absorption data can then be calculated by the expression,

$$\alpha(\lambda) = (b_2 - b_1)^{-1} \cdot \ln[\tau(\lambda, b_1)/\tau(\lambda, b_2)] \tag{21}$$

which is derived from Eq. (12) and is independent of $r(0)$. However, since such data are lacking, it is obvious that the calculation of the spectral absorption coefficient can alternatively be performed directly from Eq. (12) as a function of the spectral normal transmission $\tau(\lambda, 0)$ and the reflection loss coefficient $r(0)$,

$$\alpha(\lambda) = [2 \ln[1 - r(0)] - \ln \tau(\lambda, 0)]/b \tag{22}$$

Spectral transmission measurements can be performed in the laboratory using a suitable near and far IR radiation spectrophotometer, involving a collimated light source with flat response detector and an intergrating sphere to allow measurement of the forward scattered radiation. The measurement procedure is generally based on a single passage of the spectrophotometer beam through the polymer sheet, or the passage through a multiple number of sheets cut from the same specimen being cemented together with the minimum amount of liquid cement of the same refractive index under pressure.

A reasonably wide wavelength range would be desirable, especially for calculation of the transmittance from low temperature radiant sources. Unfortunately, spectral data corresponding to a wide far IR region of the spectrum are usually scarce, and one has to rely on existing data or incomplete measurements, sometimes of questionable reliability, which sporadically appear in the literature.

The radiation spectrum of most polymers contains a large number of resonances in the near and far IR parts of the electromagnetic spectrum. This is attributed to the molecular structure of most polymers, which is fundamentally composed of randomly oriented, long chain polymeric molecules, the excitation of the radical bonds of which usually causes a large number of sharp resonances.

Measured results from various sources have sporadically appeared in the literature, as for example from Dietz [19], Tien et al. [11], Catalanotti et al. [8], Eldin [20] and Meinel and Meinel [21]. Most of them refer to spectral extinction plots of usually unknown accuracy and resolution for specific polymer film materials of fixed thicknesses, and only a very few measurements correspond to a quite broadband range of wavelengths (up to 50 μm, Tien et al. [11]). The size of published plots and the type of scales, which, for clarity, are usually logarithmic or linear with different scale sections for specific wavelength bands, lead to extreme compilation difficulties and associated errors. However, the deficiency of gathering, correlating and exploiting measurements of this kind from a broad range of literature sources is mainly attributed to the relatively low reliability and accuracy of the data. Such data were usually derived from different laboratories at different times and specimen thicknesses for various wavelength ranges, using possibly completely different instruments, hardware and measurement procedures under different laboratory conditions. In addition to this, the major drawback is probably due to the differences between specific samples of the same material on which the measurements were performed. Even slight differences in the quality and chemical composition of the samples, usually known under the same international trade name, may be quite significant for the measurements, something which makes the task of gathering data from a wide range of bibliographical sources quite questionable.

For these reasons, the selection and use of the spectral transmittance measurements reported by Meinel and Meinel [21] was finally approved. These measurements were derived from slightly

exposed samples of real experimental solar collector glazing systems, were performed by the same laboratory equipment as a part of the same laboratory investigation and correspond to film thicknesses typically employed in solar collector technology. They were reported in the form of clear readable plots of adequate size and correspond to a broad range of polymer film materials, which are usually employed in industry, like plexiglass, fiberglass, polycarbonate, polyethylene, polypropylene, tedlar, mylar, kapton and vinyl. The spectrum of the IR radiation, although not very wide, is sufficiently large, covering the range between 2.5 and 15 μm. The measured values of the spectral transmission include also the reflection losses and can rather be considered as conservative, owing to the measurement procedure using a collimated beam instrument.

The plots were digitally scanned, and the spectral transmission data were compiled with a wavelength resolution of 0.1 μm. The 125 data for each polymer material were stored in particular data files and were employed for calculation of the spectral absorption coefficients through Eq. (22). The derived spectral transmission data files were plotted and are comparatively shown in Figs. 1–3.

A broad short IR wavelength transmission band between 2.5 to about 7 μm can be seen in Fig. 1 for the tedlar and kapton films. This band is followed by the low transmission region between about 7 to 13 μm, where both films are almost opaque. The spectral transmission of fiberglass in the same plot indicates a negligible transmission in the entire wavelength range, except for the band edges, where the transmission is higher.

The remarkable transparency of polyethylene and polypropylene films in almost the entire IR spectrum can be seen in Fig. 2 with strong resonances in the range between about 6 and 13 μm, while plexiglass is completely opaque between about 5 and 12 μm. In Fig. 3, the significant transparency of vinyl, mylar and the lower transparency of polycarbonate up to the wavelength of
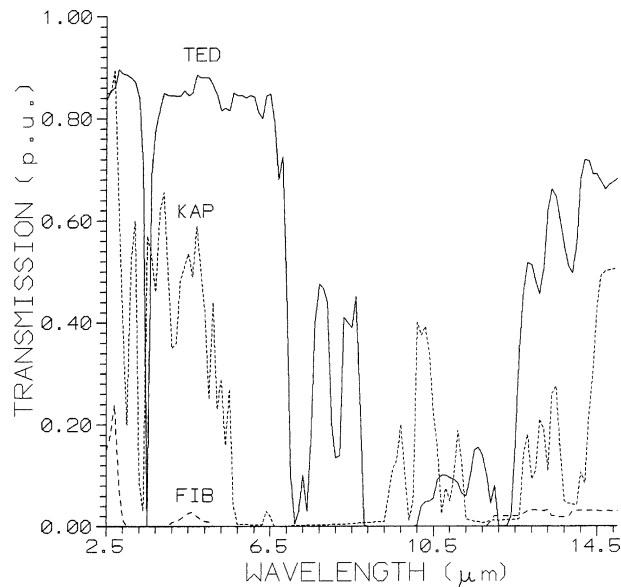

Fig. 1. Spectral transmission data for tedlar (TED), kapton (KAP) and fiberglass (FIB) films of 0.05, 0.13 and 0.96 mm thickness, respectively.
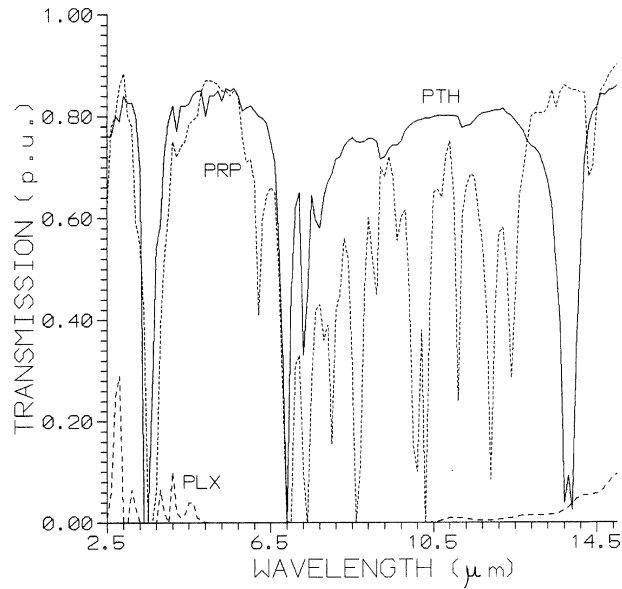
Fig. 2. Spectral transmission data for polyethylene (PTH), polypropylene (PRP) and plexiglass films of 0.13, 0.13 and 1.52 mm thickness, respectively.
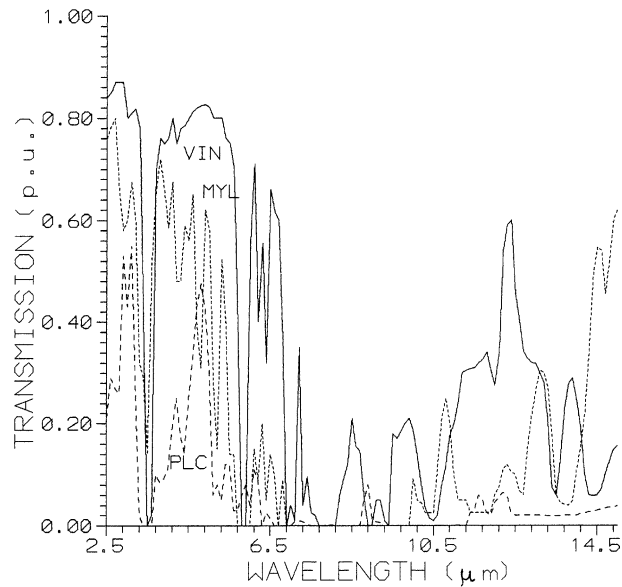

Fig. 3. Spectral transmission data for vinyl (VIN), mylar (MYL) and polycarbonate (PLC) films of 0.125, 0.13 and 1.22 mm, respectively.

7 μm can be seen with strong resonances of the three films in the short and long part of the IR spectrum.

5. Results and discussion

A computer program was initially developed to read all the spectral transmission data files, then calculate and store the spectral absorption coefficient data for each polymer material based on Eq. (22). Next, it calculates and stores the normalized black body spectral emissive power data files $I(\lambda, 0)$ at fixed radiant source temperature from Planck's law. These files are employed by the developed code for numerical calculation of the integral Eq. (20), which offers the total transmittance of a given film thickness at the specified wavelength domain for a fixed black body temperature, using the compounded Simpson's method. The integration limits are necessarily imposed by the lower and upper boundaries of the available absorption coefficient wavelength band between 2.5 and 15 μm. The calculation of the total transmission values is repeatedly performed throughout Eq. (20) for radiant source temperatures ranging between 0 and 600 °C at 25 °C intervals.

In Figs. 4–12, the total transmission of various polymer film samples are shown for radiant source temperatures ranging between 0 and 600 °C. The selected film or sheet thicknesses for each material are either standard or are often commercially available.

In Figs. 4–6, the derived transmission of three thicknesses of fiberglass with $d = 0.5$, 1.0 and 3 mm, kapton with $d = 0.1$, 0.2 and 0.5 mm and tedlar with $d = 0.05$, 0.1 and 0.25 mm are shown, respectively. Comparative inspection of the three plots indicates clearly a relatively lower IR transmission for fiberglass, which is attributed to the corresponding lower spectral absorption coefficients of this film. At the same time, the minimum transmission for the fiberglass material occurs at radiant source temperatures around 200 °C, while this minimum for kapton and tedlar occurs at lower than 100 and 0 °C temperatures, respectively. This temperature shift is attributed
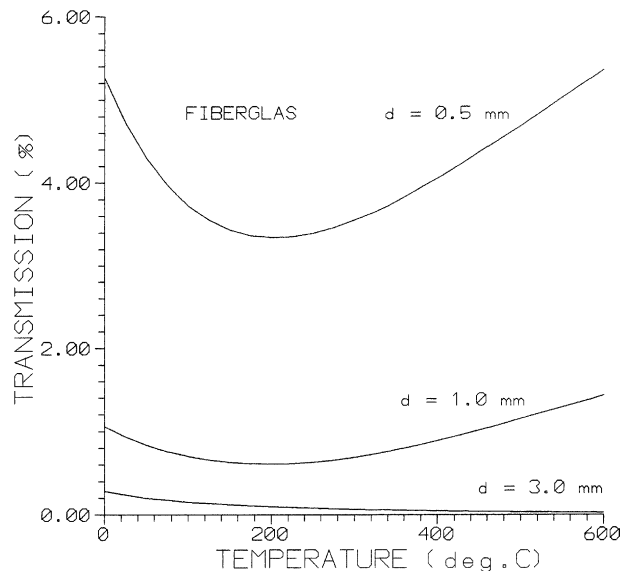

Fig. 4. The calculated total transmission for fiberglass sheets of 0.5, 1.0 and 3.0 mm thickness for a radiant source temperature ranging between 0 and 600 °C.
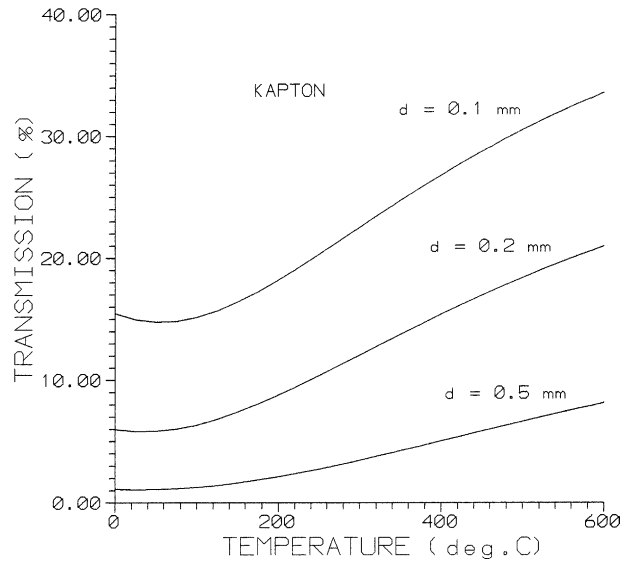
Fig. 5. The calculated total transmission for kapton films of 0.1, 0.2 and 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.
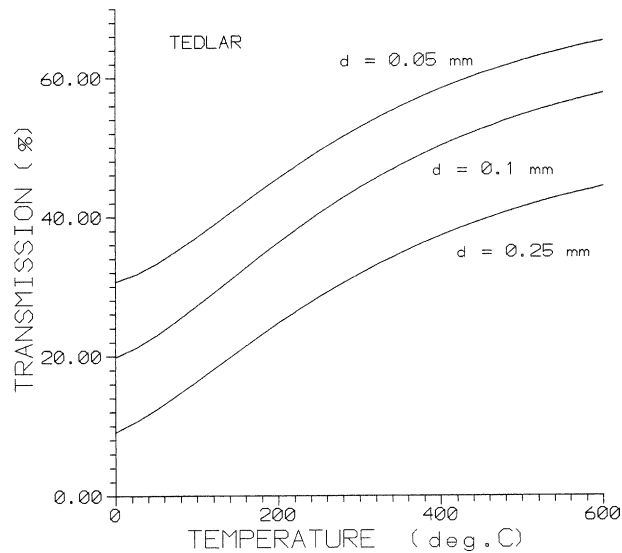

Fig. 6. The calculated total transmission for tedlar films of 0.05, 0.1 and 0.25 mm thickness for a radiant source temperature ranging between 0 and 600 °C.

to the corresponding shift of the very low spectral transmission bandwidth of the three materials towards longer wavelengths as shown in Fig. 1. More specifically, while this band for the fiberglass is between about 2.6 to 12 μm, it lies between about 5.5 and 13 μm, and 7 and 13 μm for kapton and tedlar, respectively. This wavelength shift leads to the reduction of energy trans-
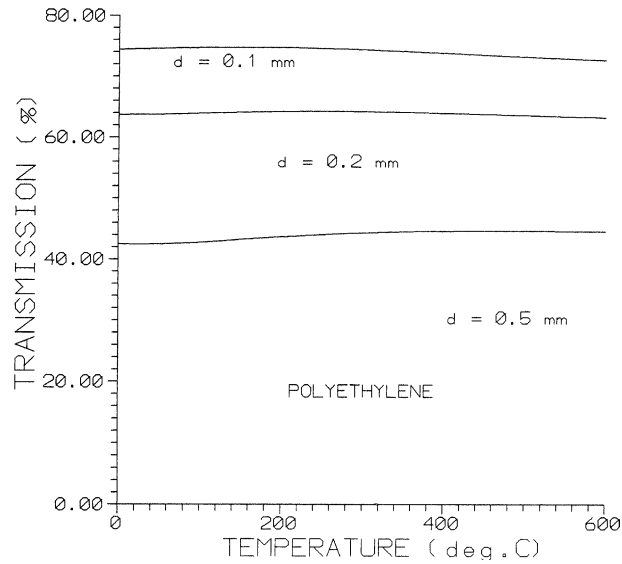
Fig. 7. The calculated total transmission for polyethylene films of 0.1, 0.2 and 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.
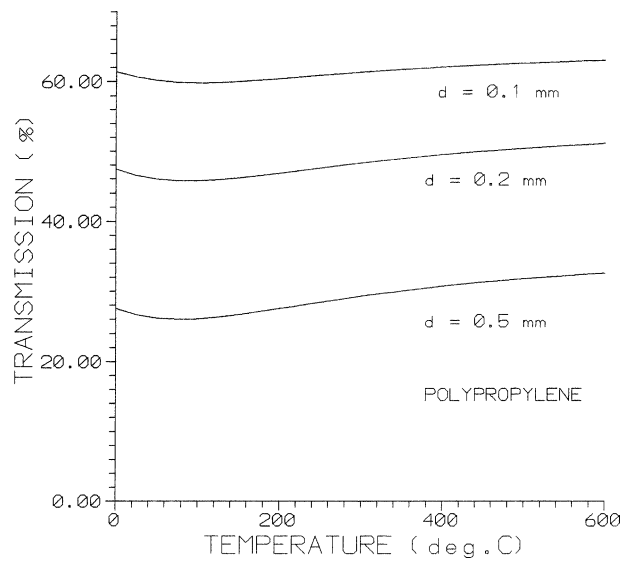

Fig. 8. The calculated total transmission for polypropylene films of 0.1, 0.2 and 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.

mission from the lower temperature radiant sources and shifts the minimum total transmission towards lower radiant source temperatures.
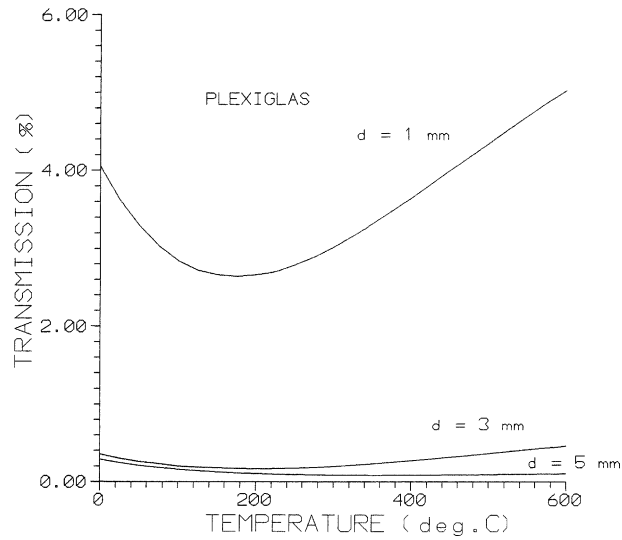
Fig. 9. The calculated total transmission for plexiglass sheets of a 1.0, 3.0 and 5.0 mm thickness for a radiant source temperature ranging between 0 and 600 °C.
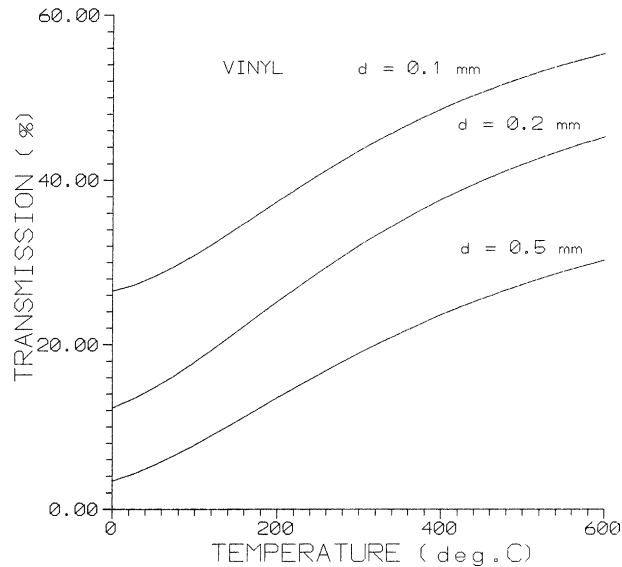

Fig. 10. The calculated total transmission for vinyl films of 0.1, 0.2 and 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.

In Figs. 7–9, the derived total IR transmission of polyethylene, polypropylene and plexiglass are shown, respectively. The three curves in each plot correspond to thicknesses of 0.1, 0.2 and 0.5 mm film for polyethylene and polypropylene, while they correspond to 1, 3 and 5 mm sheets for plexiglass. It is remarkable to note in Figs. 7 and 8 that in contrast to the shape of the curves in
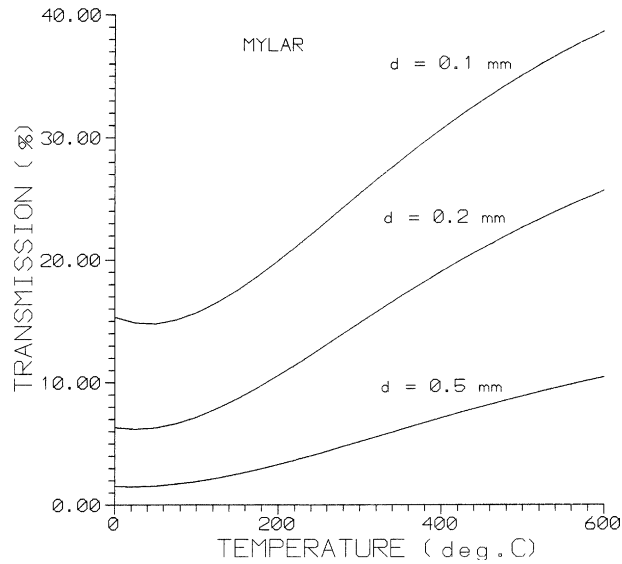
Fig. 11. The calculated total transmission for mylar films of 0.1, 0.2 and 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.
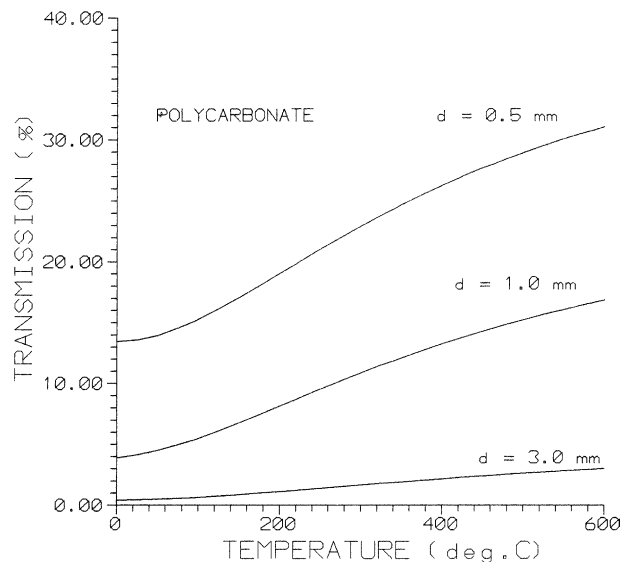

Fig. 12. The calculated total transmission for polycarbonate sheets of 0.5, 1.0 and 3.0 mm thickness for a radiant source temperature ranging between 0 and 600 °C.

Figs. 4–6, the derived total transmission for polyethylene is uniform, while it is almost uniform for polypropylene over the entire range of radiant source temperatures. This is attributed to the

almost uniformly high spectral transmission for both materials, with the exception of strong resonances for polypropylene film in the whole IR wavelength region under consideration. At the same time, the shape of the total transmission curve for plexiglass in Fig. 9 exhibits a minimum total transmittance at a radiant source temperature around 180 °C, similar to those in Fig. 4, which is attributed to the considerable region of negligible spectral transmission for plexiglass between about 4.5 and 11 μm.

In Figs. 10–12, the derived total IR transmission of vinyl, mylar and polycarbonate are also shown, respectively. The three curves in each plot correspond to thicknesses of 0.1, 0.2 and 0.5 mm for the first two materials and to thicknesses of 0.5, 1.0 and 3.0 mm for polycarbonate. Again, the shape of the curves with a minimum total transmission at low radiant source temperatures is attributed to the corresponding shape of the spectral transmission curves in Fig. 3, in which, although strong resonances are present, the bandwidth of the very low transmission ranges between about 6.5 to 14.5 μm.

The suitability of various polymer films as glazing materials in various engineering applications can be evaluated by comparison of the total IR transmissions, which determine their potential for use in passive solar design, solar collectors, radiative cooling and space and greenhouse heating design. Towards this aim, the total transmission was calculated for all the materials at a fixed thickness of 0.5 mm, and the results were comparatively plotted in Fig. 13. Inspection of the curves in this figure indicates a general trend of higher transmission at higher radiant source temperatures up to 600 °C. This is attributed to the general characteristic of higher transparency of all polymer materials at the short IR wavelength region between 2.5 and 7.0 μm as shown in Figs. 1–3. For lower temperatures, there is a reduction of transmission which is followed by a further increase at ambient and even lower temperatures. This is attributed to the significant transmission of most materials for wavelengths higher than about 12 μm, which follows the low transmission window between about 7.0 to 12.0 μm. Polyethylene, with an almost uniform very
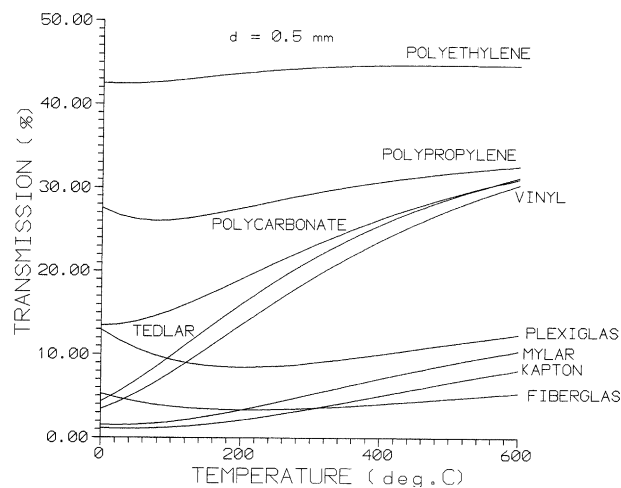

Fig. 13. The calculated comparative total transmission of polyethylene, polypropylene, polycarbonate, tedlar, vinyl, plexiglass, mylar, kapton and fiberglass films of 0.5 mm thickness for a radiant source temperature ranging between 0 and 600 °C.

high transmission, and in a lesser degree polypropylene, with a strong resonance high transmission band between 7.0 and 12.0 μm, are distinctively exempt from this general trend. This is the reason for the high transmission, about 43% for polyethylene and almost 30% for polypropylene films of 0.5 mm thick, as shown in Fig. 13, which makes them suitable for use as convection suppression very small thickness windscreens in radiative cooling applications. It can also be seen that although the total transmission for tedlar and vinyl of about 13% is slightly higher than those of fiberglass, mylar and kapton, the five materials are suitable for low and medium temperature solar collector design applications.

6. Conclusions

An analysis was developed for calculation of the total infrared transmission of various polymer films for a broad range of radiant source temperatures ranging between 0 and 600 °C. The calculation of this important radiative property requires the use of reliable spectral transmission data for a large number of film samples for a wide range of wavelengths. A series of reported spectral transmission measurements performed on a large number of polymer film samples from real solar collector glazing systems was employed to derive spectral absorption data files, which were employed for calculation of the total transmission of polymer films for a fixed film thickness. The results from the numerical integrations were plotted in the form of total transmission curves as a function of the radiant source temperature for a fixed film thickness. Comparative presentation of the derived results for all polymer film samples indicate a highest transmission for polyethylene and polypropylene while a minimum transmission for materials like fiberglass, kapton and mylar. While certain materials indicate a minimum total transmission for a region of radiant source temperatures, some others exhibit an almost uniform total infrared transmission irrespectively of the radiant source temperature, as happens with polyethylene, something which is attributed to the shape of the corresponding spectral transmission plots and reflects the specific physical characteristics of the film material.

The derived comparative total transmission for the whole range of polymer film materials could be a valuable tool for the design, calculation of thermal radiation and heat exchange balances in glazing systems of solar collectors and radiative cooling devices, as well as greenhouse and passive design structures.

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