Ultra-Violet Spectral Transmittance of Low-Density Polyethylene Film

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ABSTRACT

A calculation technique which is based on the Bouguer-Beer light absorption relationship and published spectral absorbance data of 2-hydroxybenzophenone derivative was developed for predictive determination of UV transmittance of stabilized low-density polyethylene (LDPE) film. A linear regression equation of the solar UV spectral absorbance was calculated, and the average ultra-violet transmittances for normal incident direct radiation of 0.1 mm and 0.2 mm thickness LDPE films were found to be 0.74 and 0.569 respectively.

INTRODUCTION

One of the chief defects to which most plastic films, including low density polyethylene (LDPE) film, are prone is photodegradation, a reaction involving the extraction of unreactive hydrogen atoms from the molecules when these molecules are exposed to either the shorter and more photo-chemically active ultra-violet radiation between 290 and 400 μm or to the less active visible radiation between 400 and 700 μm.

Another option is the ultra-violet stabilized LDPE film which trades off between durability and solar transmittance. The addition of ultra-violet radiation absorbers to the LDPE film is made principally to improve photo-stability and durability. But the stabilized film has a lower solar ultra-violet transmittance than the pure LDPE film because of the high spectral absorbance of the ultra-violet light absorbers. The transmittance in the infrared wavelength range (between 700 and 2500 μm) is not affected. Hence the stabilized film is transparent to the incident solar radiation but immune to the destructive effect of solar UV radiation, and suitable for long-term outdoor weathering uses as solar collector and horticultural films.

UV absorbers must meet the basic requirements [1]: (i) they should absorb 300-400 um wavelength radiation more readily than the substrate polymer, (ii) they should not react with the polymer, (iii) they should transform absorbed energy into a harmless form, i.e., energy corresponding to high wavelength of thermal energy that does not heat the polymer above its decomposition temperature, (iv) they should be stable, i.e., capable of absorbing radiative energy without undergoing decomposition.

Two well-known ultra-violet absorbers are commercially used with LDPE films, namely (i) carbon black which is an antioxidant and screening agent, (ii) derivatives of 2-hydroxybenzophenone such as 2-hydroxy-4-(octyloxy) benzophenone which acts as absorber. Mlinac, Rolich and Bravar [2] have compared stabilized and pure LDPE films irradiated by ultra-violet light and

found poorer ageing characteristics, i.e., elongation to break and stronger tendency of crosslinking of pure LDPE film. According to Hawkins [3], the addition of carbon black to LDPE film reduces penetration of ultra-violet radiation into the polymer matrix and protects against thermal oxidation.

Fuller and Cooper [4] have experimentally measured the solar transmittance of 0.15 mm thick clear polyethylene film over a wide range of incident angles. Measurements were made with a simulated radiation source approximating the solar spectrum of air mass two, from 300 to 2200 μm at incident angles of 0, 10, 20, 30, 40, 50, and 60 degrees. They found high solar transmittance values between 80 to 91 percent for the film.

Although experimental methods of finding spectral transmittance of plastic films are well established, the use of artificial radiation sources, i.e., UV lamps to approximate terrestrial radiation limits accurate prediction of performance and durability tests. Moreover, no comprehensive calculated results have been reported in the literature. In this paper, a useful method of predictive calculation of the solar UV transmittance of stabilized LDPE films is discussed, based on the published data of the spectral UV absorbance, the concentration of the UV light absorber, and the spectral normal incident radiation intensity of terrestrial UV radiation.

Table 1. Spectral optical properties of ultra-violet stabilized low-density polyethylene films.

Wavelength	Absorbance	Mass Absorption Coefficient	Transmittance	
μm		(cm²/g)	0.01 cm	0.02 cm
290	0.71	109.44	0.36	0.13
295	0.68	103.99	0.38	0.15
300	0.64	98.54	0.40	0.16
305	0.61	93.09	0.42	0.18
310	0.57	87.64	0.45	0.20
315	0.54	82.19	0.47	0.22
320	0.50	76.74	0.49	0.24
325	0.46	71.29	0.52	0.27
330	0.43	65.84	0.54	0.30
335	0.39	60.39	0.57	0.33
340	0.36	54.93	0.60	0.36
345	0.32	49.48	0.63	0.40
350	0.29	44.03	0.67	0.44
355	0.25	38.58	0.70	0.49
360	0.22	33.13	0.74	0.54
365	0.18	27.68	0.77	0.60
370	0.15	22.23	0.81	0.66
375	0.11	16.78	0.86	0.73
380	0.07	11.33	0.90	0.81
385	0.04	5.88	0.95	0.90
390	0.003	0.43	0.99	0.99

THEORY AND METHOD

Figure 1 shows the absorption curve of the 2-hydroxybenzophenone UV absorber [5]. The absorbance is maximum near 290 µm at which its value is 0.75 and decreases with increasing wavelength until a minimum near 390 µm is reached. It follows that the LDPE film containing UV absorber may have a transmittance which is wavelength dependent in the 290 to 390 µm wavelength range. The following steps were used to find the spectral transmittance of the LDPE films over the solar ultra-violet wavelength.

(a) A linear regression equation (1) is fitted to represent closely the spectral absorbance curve of the UV absorber as shown in Fig. 1.
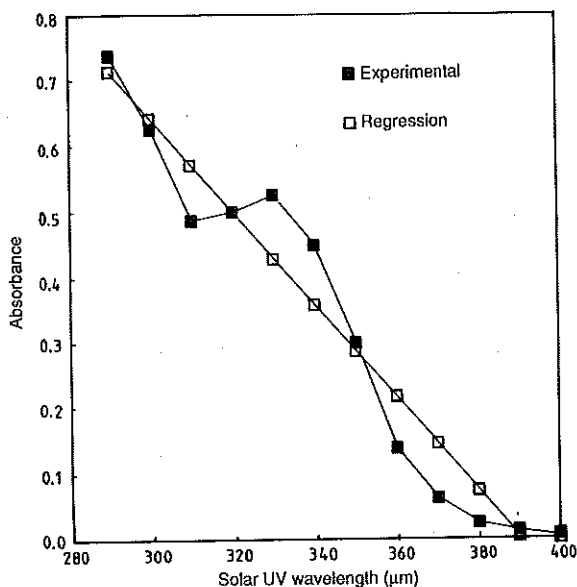

Fig. 1. Absorption spectra of 2-hydroxybenzophenone derivative.

$$A = -0.0071 (\lambda - 345) + 0.3223 \tag{1}$$

(b) A bouguer-Beer relationship of monochromatic absorption is assumed valid, i.e., the fraction loss (dI/I) of the intensity when radiation passes through an infinitesimal thickness dx of the film is proportional to dx, so that:

$$dI / I = -K_\lambda \, \rho \, dx \tag{2}$$

where K_λ is the wavelength-dependent spectral mass absorption coefficient of the film assumed to be the same as that of the benzophenone derivative, and ρ is the density of the film.

Integrating (2) and rearranging of the terms lead to

$$I_x / I_o = \exp(-K_\lambda \, \rho X) \tag{3}$$

I_x and I_o are the intensities of the emergent and the incident radiations. Losses by scattering and reflection are neglected.

(c) The spectral transmittancy is the ratio of I_x over I_o [6], and is dependent on K_λ which can be found by

$$K_\lambda = 2.303 \, (A/bc), \tag{4}$$

where A is the spectral absorbance calculated from equation (1), b is the absorption cell thickness given as 0.1 cm, and c is the concentration of the UV absorber given as 0.15 gm per litre.

(d) The spectral transmittance of the LDPE film can be found by substituting K_λ into equation (3). The average ultra-violet transmittance for direct radiation at normal incidence is calculated by the method of Duffie and Beckman [7], i.e., integrating the product of spectral transmittances and incident direct ultra-violet radiation intensity from 290 to 395 microns, then weighted by the integration of the incident ultra-violet radiation intensity also from 290 to 395 μm.

The incident radiation intensity was taken from Thekaekara's tabulated air mass one, solar UV spectral direct irradiance for wavelengths from 290 to 395 μm at ground level of USA urban and industrial conditions [8].

RESULTS AND DISCUSSION

Figure 2 shows the percent spectral transmittance plotted against wavelength for 0.1 mm and 0.2 mm thickness UV stabilized LDPE films. The films have a very low transmittance value at
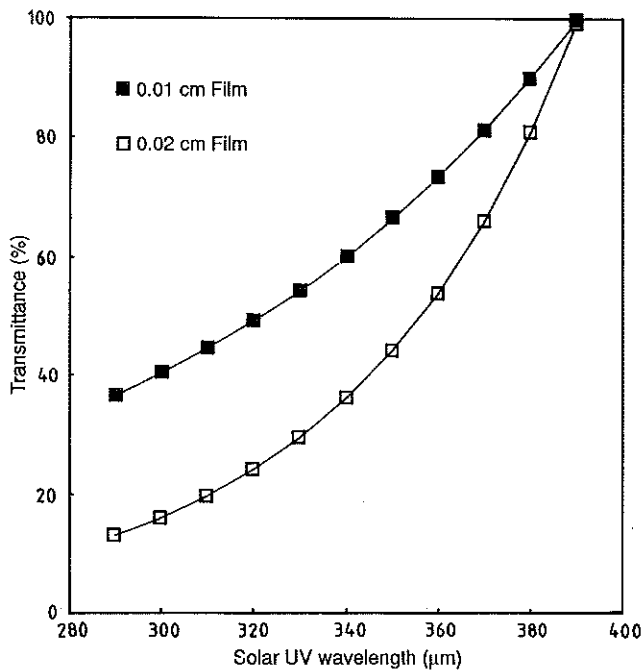

Fig. 2. Spectral transmittancy curves of stabilized LDPE films.

290 μm because of the high mass absorption coefficient, i.e., strong UV light absorption in the presence of an UV absorber. The spectral transmittance also increases with increasing wavelength, and is transparent to wavelengths longer than 395 μm. Therefore the LDPE films is unlikely to absorb in the visible range of the solar spectrum.

The average monochromatic ultra-violet transmittance at normal incidence of the 0.2 mm LDPE film was determined numerically from Fig. 3. The areas corresponding to the upper and lower curves were integrated, and the ratio of the smaller area to the bigger area is the average UV transmittance, found to be 0.569. The same procedure was repeated for the 0.1 mm film and a higher average transmittance of 0.74 was found. High transmittance was associated with thinner film because of the exponential ultra-violet absorption effect with thickness. It is obvious that a longer useful life may be expected by using a thicker film which absorbs more UV radiation.

The photostabilization effect of the benzophenone derivative in the LDPE film is complex and beyond the scope of this paper. However, the conjugated structure and the ability to form intramolecular hydrogen bond of the 2-hydroxybenzophenones may give a low energy path for light energy to be degraded to heat through the breaking of the hydrogen bond.
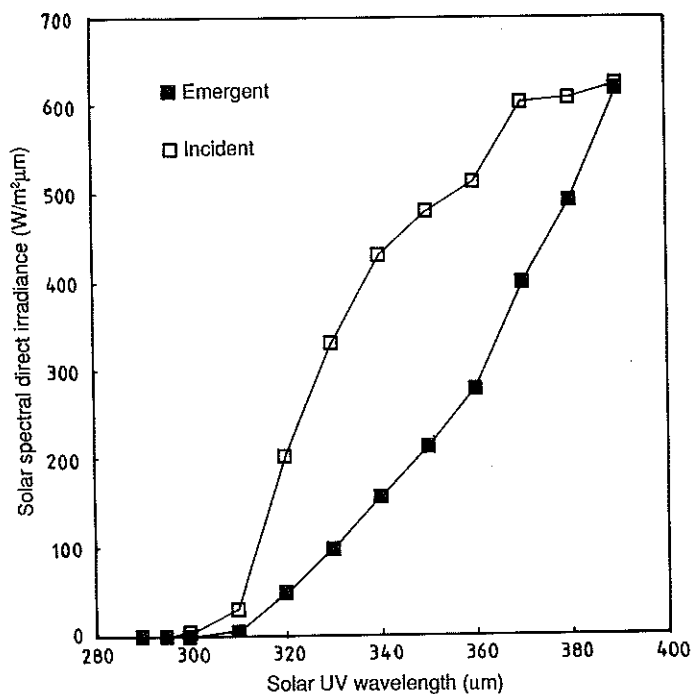

Fig. 3. Incident and transmission irradiance curves of 0.2 mm LDPE film.

CONCLUSIONS

2-hydroxybenzophenone derivative as ultra-violet light absorber improves the light stability of LDPE films. The thickness of the films could be used advantageously to reduce the monochromatic spectral transmittance under solar ultraviolet irradiance. Thus, the combination of ultraviolet absorber and thickness of stabilized films represents a practical means of possible long-term use of LDPE films.

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