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Experimental transmittance of polyethylene films in the solar and infrared wavelengths

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ABSTRACT

The growing use of plastic film coverings in agriculture is due to the possibility of increasing the air temperature around the plants, reducing radiative and convective energy losses, protecting fruit trees from adverse weather conditions, reducing fungal diseases, assuring less reliance on herbicides and pesticides, better protection of food products and more efficient water conservation. Low-density polyethylene (LD-PE) is one of the most widely used plastic films for greenhouse coverings, low and medium tunnels and soil mulching. In this paper, we present radiometric properties of a new and old (used for more than five years) LD-PE film, experimentally investigated using different methodological approaches for different wavelength bands, especially at medium IR. Experimental measurements in the IR wavelength spectrum, included the Near (0.78–3 µm), i.e. N-IR-A (0.78–1.4 µm) and N-IR-B (1.4–3 µm) and Medium (3–50 µm) in accordance with ISO 20473 (E) 2007 were carried out. Experimental results obtained are in agreement with those in the literature and show that the aging effects are minimal in the plastic film used for five years. This finding is crucial for greenhouse design. Referring to practical applications, energy balance of an ordinary agricultural greenhouse was also evaluated. The authors believe that this research results on all the optical properties in a wide spectral range of LD-PE will be useful not only in agriculture, but also for any other solar engineering application.

1. Introduction

The aim of this research is to provide an analysis of radiative properties of LD-PE film for greenhouse covering, using experimental tests based on a different methodological approach for each wavelength band measurement. In particular, the investigation was carried out in the field of Near and Medium Wavelengths of Infra-Red radiation in accordance with ISO 20473 (E), 2007 (ISO 20473 (E), 2007 Optics and photonics. Spectral bands) testing two films, one new and the second old, of the same type (i.e. respectively, the first produced recently and without ageing and use effects, the second, the old film, used for at least five years). In particular, the effects of ageing of the LD-PE film, were evaluated. After a literature research, the authors realized that in the field of Long Wavelengths of Infra-Red radiation (LW-IR) few experimental data are available. Experimental values we present here refer to some films used as covering of existing plant/flower conservatories. In particular, LD-PE long life films of 200 µm thickness and polyethylene stabilized to ultraviolet ray films supplemented by hindered amine light stabilizers (HALS or HAS) were studied to assess their reflectance and transmittance percentage of the Visible Radiation in the wavelength range of 300–2400 nm. Furthermore, the same plastic films were analyzed to measure the hemispherical transmittance and reflectance percentages in the LW-IR, both in the range of 1.6–15.6 µm, 0.2–17 µm until 19 µm with a correspondent different experimental approach for each band wavelength. The experimental investigation of the studied films transmittance in the above IR wavelength ranges compared to the transmittance in the visible spectrum allowed the proper evaluation of their radiative thermal properties and then their greenhouse effect ability and effectiveness, that is fundamental to reduce energy needs in cold climates and winter time as highlighted in Zhang et al. (1996).

2. Background

The knowledge of the total Infra-Red (IR) transmission of polymer films is very important for engineering applications and the agricultural sector. Total IR transmission assures polymer film suitability and efficacy at a given temperature level. Many literature studies highlight the present technological and process innovations applied to the agricultural sector both for plants/flowers and agri-food/vegetables under the controlled conditions provided by greenhouses. In literature field

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experimental studies have been developed for the assessment of solar radiation transmittance, heat loss reduction, high structural strength, material durability and sustainability, energy consumption reduction, efficient ventilation, indoor microclimatic parameters and air ventilation control, implementation, management and maintenance costs but also environmental impact reduction (Zhang et al., 1996; Njoroge et al., 2014; Sartore et al., 2013; Scarascia-Mugnozza, 2003). Furthermore, some studies have addressed the effects on the air humidity and temperature of greenhouses and connected energy consumption due to plants/flowers growth (Schettini et al., 2011) and, in particular, to the application of plastic films, known as Ultra-Thermic, with IR block (7–14 μm) to reduce frost risk when the greenhouse is not heated and energy consumption when a heating system is used (Schettini et al., 2013). Fundamental applied researches have been carried out on physical, mechanical and radiometric properties of plastic cover application for greenhouses and plant growth in Mediterranean areas (Tsilingiris, 2003; Espì et al., 2006). It is well known and also experimentally proved in situ, that Ultraviolet radiation (UV), especially for the solar spectrum (UV-A and UV-B in the wavelength range 280–400 nm) absorbed by the plastic film, is the crucial factor causing film ageing and degradation processes (Kittas and Baille, 1988); Vox and Schettini, 2013; Kamweru et al., 2014). Most recent literature investigates the radiometric properties of different innovative typologies of film used for protected crops due to constantly evolving technologies, agricultural development and automation for higher quality of flower and vegetable production, and the corresponding environmental and economic impact (Adam et al., 2005; Cemek and Demir, 2005; Schettini and Vox, 2010; Vox et al., 2005). In the research area of engineering applications, recent literature on the argument provide mathematical models, checked with the in situ measured experimental data, for e.g.: the energy balance and energy performance assessment of PV-ventilated solar greenhouse dryer for drying of typical fruit products (Janjai et al., 2009); the analysis of the thermal environment of a cultivation greenhouse combined with the indoor air flow evaluation (Serrano-Arellano et al., 2015); to estimate the cumulated global radiation inside a photovoltaic (PV) greenhouse at the desired time interval and then provide a decision design tool for the identification of the most suitable plant species referred to their light requirements (Cossu et al., 2017); to study energy performance of active solar thermal systems with phase change materials and apply them in plastic greenhouses for increasing control of the inside air temperature (Zhou et al., 2017). Most of the studies that provide experimental measurements results of the radiometric properties of different plastic films are limited to wavelength bands not useful for the energy performance and greenhouse effect efficacy assessment. E.g. the research of Hammam et al. (2007) provides an interesting performance evaluation of thin polymethylmethacrylate and photo-selective films used as solar concentrators in greenhouse applications, but the absorption and emission spectra have been experimental measured in the 200–1100 nm wavelength. One of the few study that provides radiometric coefficient, especially for the IR wavelengths band, useful for energy evaluations of plastic covering materials, is Mashonjowa et al. (2013). Others literature studies providing radiometric data of plastic films are Al-Mahdouri et al. (2014) and Njoroge et al. (2014)). In Al-Mahdouri et al. (2014) is particularly oriented to thermal performance assessment of three rectangular enclosures covered with different greenhouse materials, such as silica glass, Polyvinylchloride (PVC) and Low Density Polyethylene (LD-PE) and then, ultimately, to the energy performance of the absorbing system. The authors refer to their previous work Al-Mahdouri et al. (2013) in which they have evaluated spectral index of refraction for the plastic and glass materials studied. In order to avoid difficulty of measuring thermal emittance, they have applied the low sensitivity of the Kramers–Kronig method to the absorption index for the semi-transparent material providing a methodology to find out all the optical properties for greenhouse plastic films. They have used a method to deduce the spectral refractive and absorption indices for different plastic films in the spectra between 0.22 and 25 μm. The authors have measured diffuse hemispherical transmittance and reflectance of plastic film by spectroscopic photometry method and then they have estimated the optical radiometric indexes by inverse calculation of radiative transfer equation (RTE) solved by the Radiation Element Method by Ray Emission Model (called REM; Al-Mahdouri et al., 2013). The authors explain that for longwave radiation, the optical constants of opaque glass material can be deduced by using the Kramers–Kronig method (Al-Mahdouri et al., 2013). A model for radiative heat transfer analysis to an agricultural greenhouse has been also provided considering the covering material as a non-gray radiative one-dimension plane-parallel medium (Al-Mahdouri et al., 2013).

In the work of (Njoroge et al., 2014) the percentage IR transmission, reflection and absorptance of two polymer material films and glass, used for different solar air heater (SAH) applications, but limited in the wavelength range of 700–880 nm, were investigated. Due to the extended use of low density polyethylene (LD-PE), a hindered amine light stabilizer doped film (HALS) as cover materials in Tuscan greenhouses, we investigated two LD-PE stabilized films, one new and second old of the same type, referring to their two real working conditions i.e. clean and soiled.

We provided an experimental methodological approach for direct measurements, on all the visible and IR wavelength bands, of total transmittance, reflectance, absorptance, but also ballistic and diffuse transmittance of the studied New and Old plastic films. Experimental data analysis allowed us to evaluate the effects of ageing and degradation due to solar radiation, which were found in the higher absorption of the Old plastic film. As reported in Adelhafidia et al. (2015) photo-degradation of LD-PE films is mainly due to the UV range of solar light and can be really considered the most deleterious factor of plastic degradation in outdoor exposure.

Results comparison between the hemispherical transmittance and reflectance percentages in the long wave infrared spectrum (LW-IR) and the reflectance and transmittance percentage in Visible Radiation, showed that the optical (visible spectrum) and radiative thermal properties (LW-IR) are comparable and very similar for both the two kind of film studied. The most important factor affecting growth, development and yield of crops, but also thermal energy engineering applications, is light transmission. The experimental results show that the quite high transparence in LW-IR and MW-IR wavelength ranges of the plastic films studied (New and Old), does not produce a substantial effective greenhouse effect, even if the Old plastic shows better radiative performances.

3. Materials and methods

A light beam perpendicularly incident to the surface sample (Fig. 1) can be reflected, transmitted, absorbed, forward scattered or back

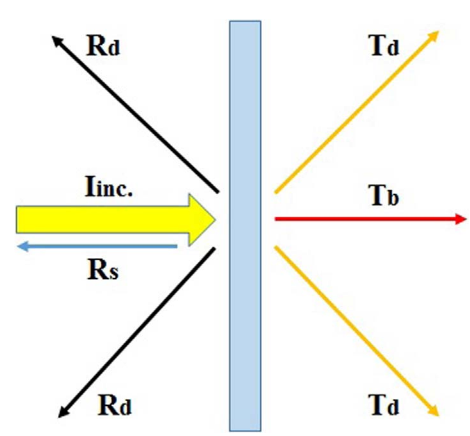

Fig. 1. Balance of radiation components on the surface with respect to the incident beam.