encit 2020

ABCM
Associação Brasileira de Engenharia e Ciências Mecânicas

18th Brazilian Congress of Thermal Sciences and Engineering
November 16-20, 2020, (Online)

ENC-2020-0647
DETERMINATION OF THE RADIATIVE PROPERTIES OF THE PLASTIC FILM (PVC)

Marcelo Borges dos Santos[a,b]
Luís Mauro Moura[a]
Vitor Loic Moura[a]
Allan Bruno da Silva[b]
Luan Roberto Bonjour[b]
[a]PUCPR – Pontifícia Universidade Católica do Paraná- R. Imac. Conceição, 1155 - Prado Velho, Curitiba, PR
[b]UNICESUMAR- R. Itajuba, 673, Curitiba, PR
engmecanica.marcelo@gmail.com
luis.moura@pucpr.br
vitor.loicm@gmail.com

Abstract. *Thin plastic film, based on PVC, is a transparent, low-cost, easy-to-handle material that can be applied as a support containing fibrous, granular, or powdery materials for analysis in order to determine radioactive properties, such as: index of refraction, reflectivity, absorptivity and transmissibility. However, the plastic film itself can substantially interfere with the measurements of the materials that are truly the objects of interest in this analysis. In order to get around this situation, these same radioactive properties were analyzed in thin plastic film so that it was possible to compute the interference of the film itself in the final result, for other tests to be done later. The work that follows in a first moment, presenting the used equations, a description about the Perkins Elmer spectrometer model 100 FT-IR & FT-NIR, that was used for the tests, being that the majority of the radiation emitted by the equipment source operates in the infrared band, which is the band responsible for thermal heating, and soon after the tests, the radiative properties of the film were determined.*

Keywords: *Plastic film, Refractive index, Reflectivity, Absorptivity and Transmissibility, Radiative properties in thin film.*

1. INTRODUCTION

Currently, countless materials, when combined, present a substantial improvement in certain desirable properties, which may be: mechanical, thermal, electrical, among many other properties. However, for these materials to be analyzed, one must have a support that is adequate and adaptable to the equipment, as some of these materials when analyzed can be in the form of: granules, natural fibers, liquids and gases. In addition to the difficulty of confining the material, one must expect that the support does not significantly interfere, in the measurements, of the properties to be determined. It was in view of these specificities that the radiative properties of the plastic film, which is the material used for confinement, of granulated materials and organic fibers, of the sample port of the Perkins Elmer Spectrum 100 FT-IR & FT-NIR spectrometer were studied.

The dimension of the thickness of the plastic film, the transparency for wavelengths in the band of visible light, the low cost, and the ease of handling, form the main motivations for determining the radiative properties of the plastic film. The properties of the film to be determined are: the transmittance of the energy, the reflectance and finally the energy absorption, the complex refractive index of the film will also be determined in this work. It is worth mentioning that it is expected that only the transmissibility has a significant value, in relation to the other parameters, as, as already mentioned, the film should only serve as a support, interfering as little as possible in the measurements of the properties of other materials to be analyzed.

The vast majority of articles cite as an example the radiative properties of radiation transmissibility through glass. Glass is transparent to visible light, but opaque to thermal radiation, which can occasionally cause thermal comfort problems, especially for buildings, just to mention: (Taleb, Wattar, 1998) who studied the properties of transmissibility of glass, for thermal comfort in buildings.

About transmissibility in thin films, we can mention: (Liang, Han, 2007), who determined the properties of thin films based on germanium and silicon, more recently we have the article by (Gertych *et al.* ,2019), which analyzed the radiative properties of MoS2-based nano-flakes, and finally, the article by (Kariper, 2017) that addressed the radiative properties in a thin film based on Manganese. All of the articles mentioned above, analyze the properties of materials for high-tech applications, but there are few articles that precisely define the transmittance of thin plastic films, common in the production of food packaging, known to be of low cost.

2. MATHEMATICAL FORMULATION

The process of refraction of light, is known as a phenomenon in which the direction of the vector propagation of the light itself is observed to change when it passes from one medium to the other. The light falls on a determined surface of separation of medium, being that a part of the incident light itself is reflected and another part is transmitted to the interior of the material. What determines the change in the direction of the propagation vector of an electromagnetic wave are the electromagnetic properties of the material itself, that is, how the material behaves when an electric or magnetic field passes through its interior. The physical magnitude that relates the electrical and magnetic properties of one medium to the other is the index of refraction, it should be mentioned that for an electric wave that propagates in a dielectric medium the index of refraction is an indentity of the complex type, because it does not there is only the change of direction, but also the attenuation of the wave as it penetrates the interior of the material. Eq. (1) presents the refractive index of an electromagnetic wave (Modest, 1993):

$$m=n+ik \tag{1}$$

Being:

m - complex refractive index;
n - real part of the refractive index;
k - imaginary part of the refractive index.

It is necessary to comment that the imaginary part of the refractive index, κ , is also called the extinction coefficient, or attenuation coeficiente.

The Poyting vector corresponds to the rate of energy intensity emitted by a light source, of an electromagnetic wave that diffuses through space. The Poyting vector is calculated through the vector product of the electric field with the conjugate of the magnetic field of the electromagnetic wave. For simplification of calculations, the average Poyting vector is used, which corresponds to the average of the energy dissipated by the wave period, and is calculated as the square of the amplitude of the electrical component present in the wave as observed by Eq. (2). For propagation in thin films, generally considered a dielectric medium, energy attenuation is expected along the path due to the Joule effect (Sadiku, 2014).

$$\vec{S} = \frac{n}{2c\mu}\left|\overrightarrow{E_o}\right| e^{-\frac{4\pi k d}{\lambda_o cos\theta_t \vec{e}_z}} \tag{2}$$

Being:

$\vec{S}$- Medium Poyting Vector;	[W/m^2]
c- Speed of light;	[m/s]
n- Real part of the medium refractive index;	
θ_t- Angle forming between the transmitted beam and the plane of incidence;	
E_0- Amplitude of the electrical component of the electromagnetic wave;	[N/C]
κ - Complex part of the refractive index;	
d - Wave path;	[m]
μ - Magnetic permeability;	[N/A^2]
λ_0- Wavelength in vacuum.	[m]

The numerical analysis of this work is based on an equipment that measures the relationship between the intensity of the total transmitted and reflected energy read by the sensor, I, in relation to the intensity of the incident energy emitted by the device's source, I_0 ,can be defined according to Eq. (3):

$$R_{film}, T_{film}\,[\%] = \frac{I}{I_o} \tag{3}$$

The Fig. (1) shows a simplified diagram of the path of the light beam, inside the material, depending on the incident energy.

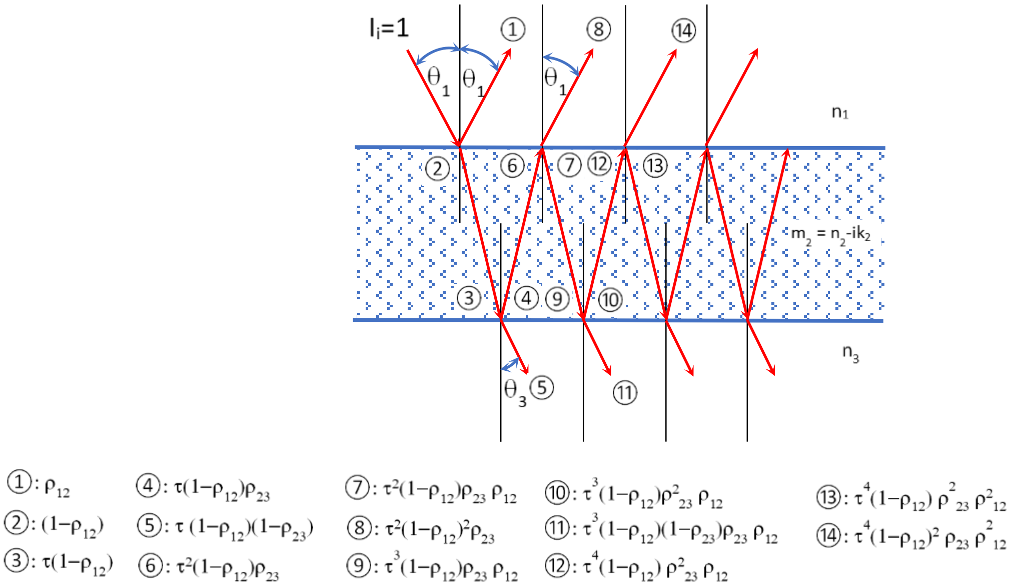


Figure 1. Simplified representation of the energy division scheme when focusing on a thin film.

Through Fig. (1), it is clear when a beam falls on the surface that divides the media, a portion of the energy tied to the incident beam is reflected and another complementary portion is transmitted penetrating the material. The partition of energy in thin films is a function of the ratio of the refractive index of one medium to the other, as already mentioned in the introduction to this section. It can be observed that, as the beam travels inside the material, it undergoes successive redistribution of energy, when it reaches the internal surfaces of the film (Modest, 1993).

Once the total reflected, transmitted energy is obtained, respectively represented by the variables, R_{film} and, T_{film}, and normalizing both according to the energy intensity of the equipment source. And considering that both medium 1 and 3, as observed by Fig. (1) correspond to the outer region of the film, be it air. It is possible to determine the reflectivity, ρ, of the material and the component related to radioactive attenuation, τ, through Eqs. (4), and (5) (Modest, 1993):

$$R_{film} = \rho\left[1 + \frac{(1-\rho)^2\tau^2}{1-\rho^2\tau^2}\right] \tag{4}$$

$$T_{film} = \frac{(1-\rho)^2\tau}{1-\rho^2\tau^2} \tag{5}$$

Being:

ρ - Reflectance of material

τ - Transmittance of material

The component responsible for the wave attenuation, expressed by the variable τ, can be determined from the Poyting vector, as shown in Eq. (2):

$$\tau = e^{-4\pi\kappa d/\lambda_o cos\theta_t} \tag{6}$$

Therefore, the absorption coefficient, also known as the wave extinction coefficient, and the complex wave refraction index is defined as:

$$\kappa = -\frac{\lambda_o ln\tau}{4\pi d} \tag{7}$$

To determine the real part of the refractive index of the plastic film, a normal type was considered for the incidence of the light beam, on the thin plastic film. The approximation occurs due to the limitations of the device, as it is not possible to read data for a perfect normal incidence, as will be properly addressed in the item on the experimental methodology, and the construction aspects of the device.

Through Eq. (8), it is possible to calculate a real part, n_2, the refractive index of the material, remembering that the medium 1, will be considered the value of the refractive index equal to 1.

$$\rho = \frac{((n_1 - n_2)^2 + k_2^2)}{((n_1 + n_2)^2 + k_2^2)} \tag{8}$$

3. DESCRIPTION OF THE EXPERIMENT

The Perkin Elmer Spectrum 100 FT-IR & FT-NIR equipment was used to carry out the experiment, with a wavelength band ranging from 0.63 to 25 μm, corresponding to the infrared, which is a special region, in which the electromagnetic waves transfer enough energy to the material body so that some form of vibration occurs between the bonds of the atoms that make up the elements. These internal vibrations are capable of appreciably increasing the temperature of the substances. For higher frequencies, and consequently lower wavelengths, we find the spectral band of the visible, which are the major lengths, corresponding spectrum of solar radiation. Even shorter lengths fit the ultraviolet that allows, ionization processes, and even breaking atomic bonds.

The equipment has a fast Fourier transform system, together with Michelson's interferometer for the treatment of the captured signal. The use of a circuit that makes the fast Fourier transform of the signal, is something extremely advantageous, since it does not require any type of auxiliary light decomposition system, which uses a rotating prism. Decomposition is necessary to obtain the infrared radiation spectrum, that is, what is the corresponding radiation intensity for a given wavelength. Another advantage is the presence of an internal system composed of concave mirrors and properly positioned lenses and filters that allow to stabilize and better concentrate the radiative beam on the sample.

The Fig. (2) shows the spectrometer used, model 100 FT-IR & FT-NIR, to determine the radiative properties of the plastic film.

Figure 2. 100 FT-IT & FT-NIR Spectrometer - Perkins Elmer Model.

The Fig. (3.a), shows the path traveled by the light beam for the transmittance test, and Fig. (3.b), shows the path of the light beam, for the reflectance test of the plastic film.

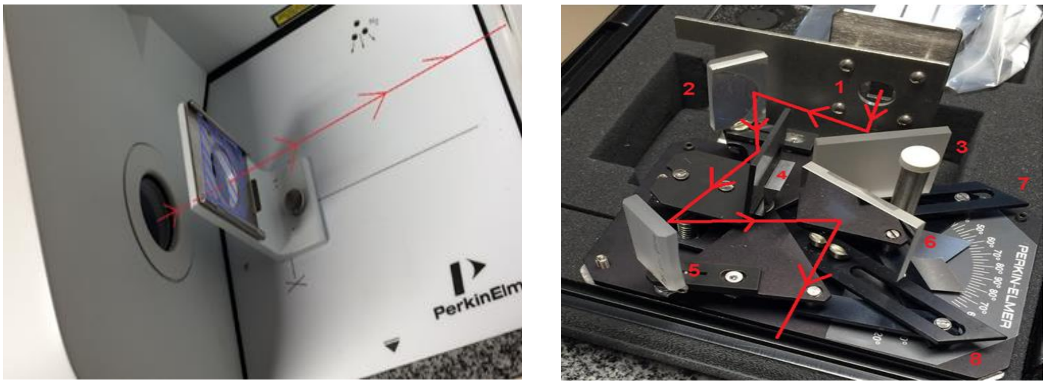


Figure 3. Path traveled by the light beam, (3.a) case of transmittance (3.b) and case of reflectance.

According to Fig. (3.b), the path of the light beam for the reflectance test can be described step by step as follows: the beam leaves the equipment and goes to the sample support apparatus (1).The beam in the sequence falls on the first reflecting mirror positioned in (3), the reflected beam leaves towards the mirror (2), after reflection the beam falls on the sample fixed in (4), the portion of the reflected beam, it directs to the mirror (5), which directs the beam towards the mirror (6), which reflects the beam in the direction of the sensor that determines the portion of the beam intensity reflected by the sample, by the energy emitted by the equipment source. The angle that indicates the positioning of the mirror (3), and (6), are determined by the mechanisms (7) and (8), respectively, for equal angles the reflectivity of the material is analyzed, for different angulation the beam spread is measured light, incident on the sample. For the transmissibility test, the process is simpler if it is described and performed, since the beam starts from the source and falls on the sample and then goes to the sensor of the equipment that reads the light intensity [4].

The material under study is commercial plastic film, also known as PVC film, used to pack food, as a means of prevention and asepsis. Its chemical composition is based on 57% sea salt, and 43% ethylene or ethylene. Fig. (4) shows the dimensions of the thickness of the plastic film used in the present work. Irregularities in the measurements are observable both due to the manufacturing process, as well as due to the inclination of the plastic film during the capture of its image, the value of the thickness of the film measured through an electron microscope was 10.4 ± 0.3 μm.

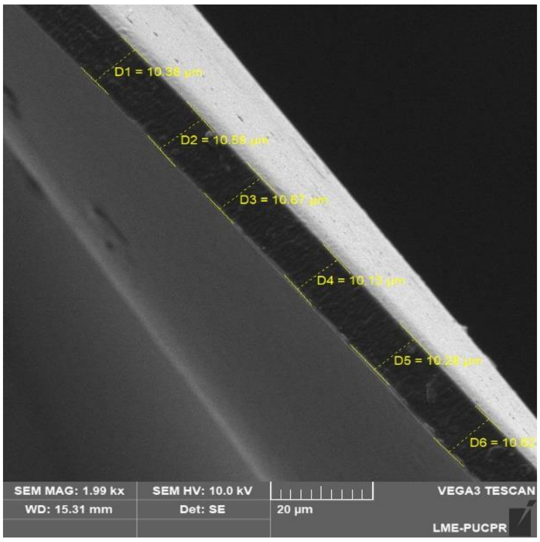


Figura 4. film thickness image

The Fig. (5) shows the blackbody curve of the equipment, which represents the radiation spectrum of the source. The greatest intensity of energy emission occurs for the wavelength of 4.26 µm, and according to Wein's Law of displacement for this determined wavelength it can be determined that the temperature of the source, which for this equipment presents the value approximately 680.29 K.

The units of measurement represented by the graph shown in Fig. (5), related to the energy emitted by the source, are energy unit characteristic of the equipment unit system itself, and are related to the units of the international length intensity rate system. waveform, presented by the Planck equation, for blackbody emission, which is measured in $W/(m^2\ \mu m)$

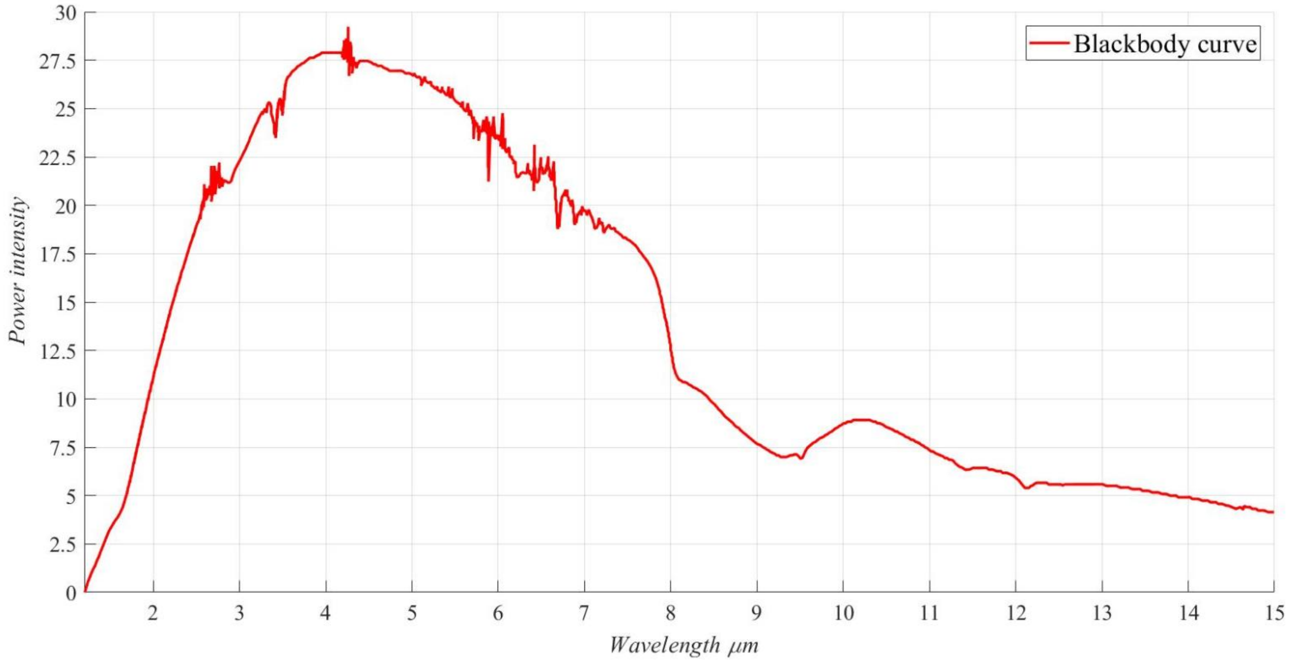


Figure 5. Spectrum of electromagnetic radiation from equipment source 100 FT-IT & FT-NIR

4. RESULTS

As previously mentioned, when a radiative beam falls on the surface of the thin film, a part of this beam reflects, another is transmitted, and a last portion is absorbed by the material itself. For the plastic film, the expectation is that the energy is practically fully transmitted, since the film serves only with physical support, to determine the radiative absorptivity of the material of a fibrous, granular, or powdered nature.

The Fig. (6) shows the relationship between the energy transmitted, and the energy emitted from the source beam of the equipment itself. To carry out the experiment, it was presented as an alternative to the PVC plastic film, the silicone film, common in cell phone cases, used to protect the device's screen. However, as shown by the graph, it is visible that the plastic film is significantly more transparent to thermal radiation, than the thin silicone film. The dividing line in bold, in Fig. (6) divides the graph into two regions, one for wavelengths below 7 µm which corresponds to 65% of the total energy emitted by the source, and another for wavelength above 7 µm. It is notorious to notice that the film is practically transparent for wavelengths below 7 µm.

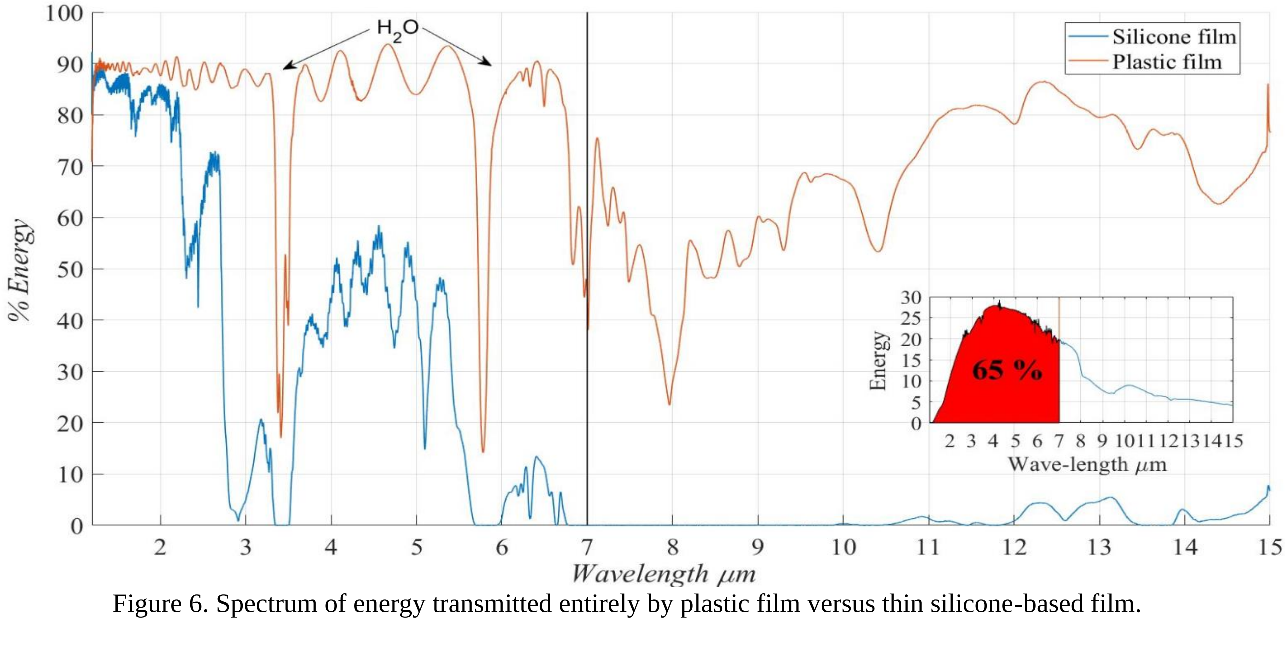


Figure 6. Spectrum of energy transmitted entirely by plastic film versus thin silicone-based film.

As noted by Fig. (6) radiation that has a wavelength of approximately 3.5. μm and 5.7. μm are absorbed by the water particles, which adhere to the surface of both films, during the test performance (Wozniak and Dera, 2007). In addition to analyzing the energy that passes through the film, it is also necessary to make an analysis of the reflectivity of the surface as a function of the different wavelengths, in order to obtain the radiative properties correctly.

The Fig. (7) presents the experimental data referring to the percentage portion of the total energy transmitted in comparison with the percentage portion of the reflected energy, for the angle of incidence of the beam on the sample of approximately 25°. This angle corresponds to the maximum possible opening of the reflectivity test stand, accommodated inside the spectrometer. It is necessary that the angulation approaches the maximum of the normal incidence, so that it is possible to calculate the real index of the refraction of light, on the plastic film as proposed by Eq.(8).

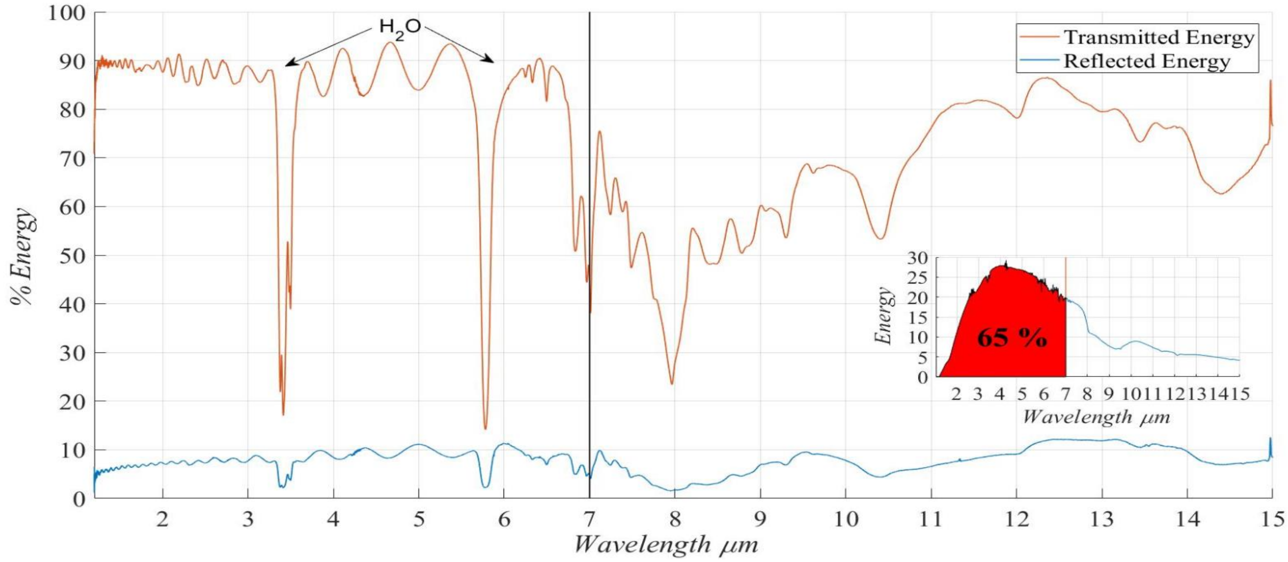
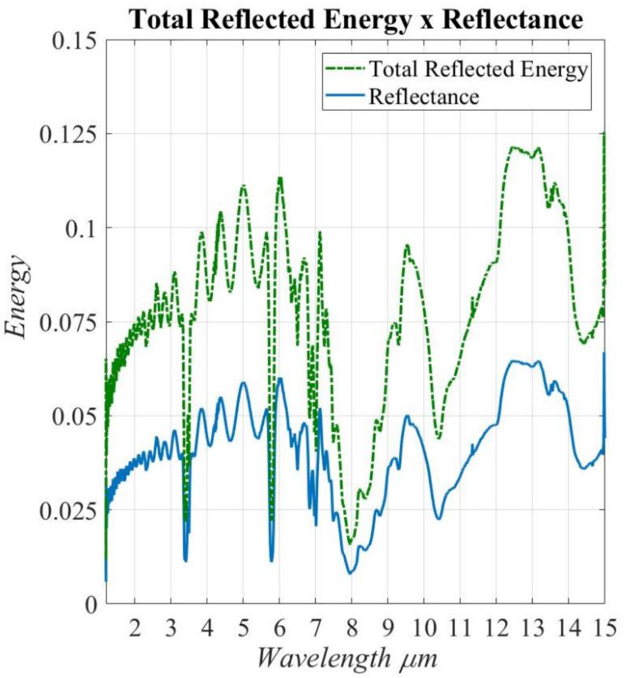


Figure 7. Spectrum of total energy reflected versus total energy transmitted from the plastic film.

From the reading of the equipment data referring to the fraction of the reflected energy and the fraction of the transmitted energy, by the total radiative energy emitted by the source, respectively represented by the variables, R_{film}, and, T_{film}.It is possible to characterize through equations 4, and 5 the properties radiative of the material, which are the reflectivity ρ and transmissibility, τ.

The Figs. (8.a and 8.b) represent the radiative properties of the reflectivity and transmissibility of the material, depending on the wavelength of the material.



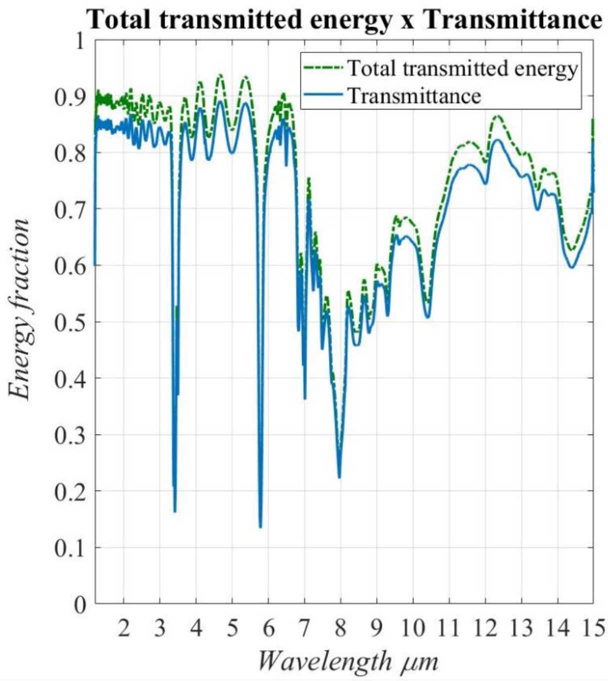


Figure 8. Relationship of the radiative properties of reflectance (8.a) and transmittance of thin plastic film of thin plastic film.(8.b).

It is important to note that through Figs. (8.a and 8.b), that the radiative properties are only slightly below the values that represent the energy fractions read by the spectrogram of the same properties to which these radiative properties refer. This occurs because the incidence beam is practically transmitted in its entirety, leaving only a tiny portion of the original beam that is confined to the material, and undergoes reflection and transmission successively, as shown in Fig. (1).

Considering the energy balance such that the incident energy is distributed in such a way that a certain fraction of it is transmitted, another absorbed by the dielectric material, and a last portion reflected back to the external environment, as proposed by Eq. (9):

$$1 = \alpha \text{ (absorptivity)} + \rho \text{ (reflectance)} + \tau \text{ (transmittance)} \quad (9)$$

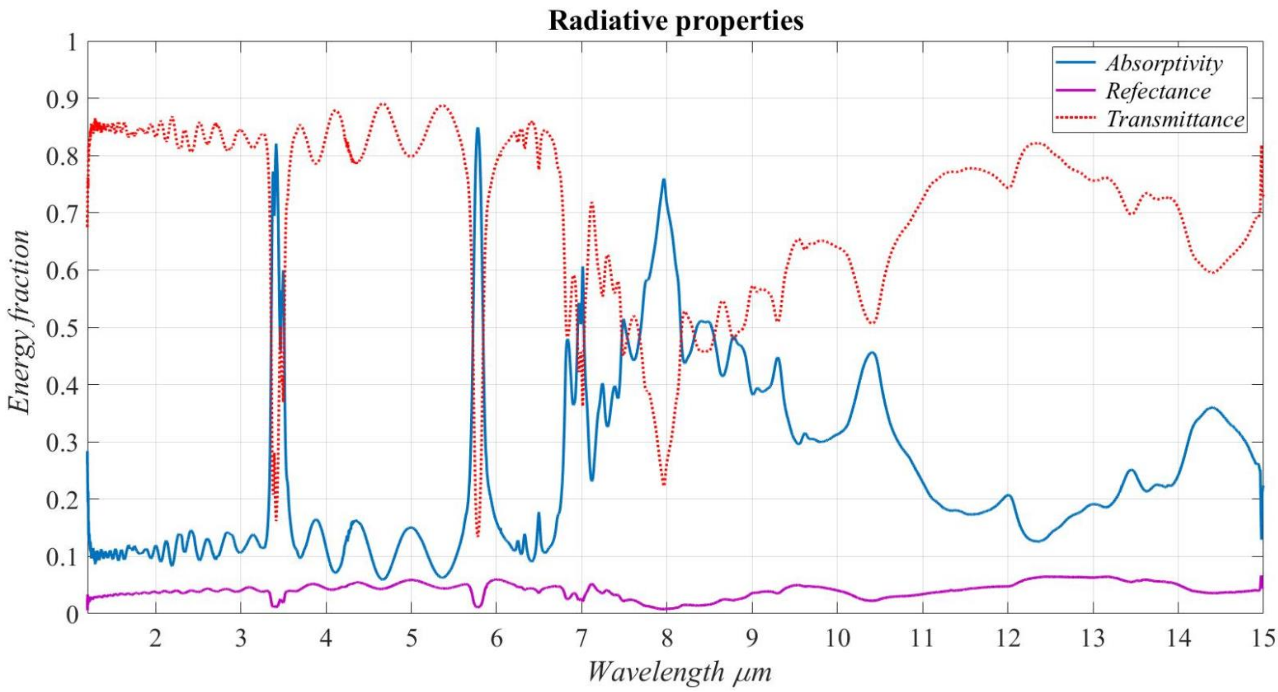


Figure 9. Radiative properties of reflectivity absorptivity and transmissibility of thin plastic film as a function of wavelength.

The Fig. (10) and (11), respectively, show the absorption coefficient, or extinction coefficient of an electromagnetic wave, and the real part of the refractive index of the plastic film, obtained through the application of Eq. (8).

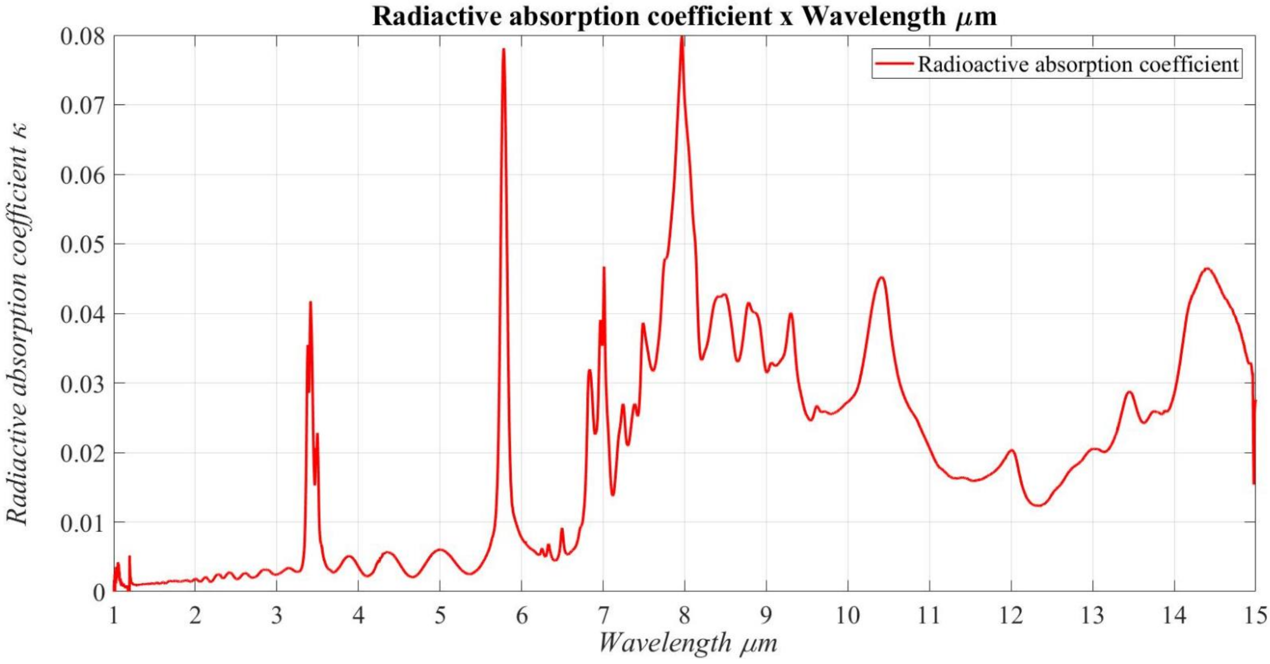


Figure 10. Spectrum of the wave extinction coefficient of PVC plastic film.

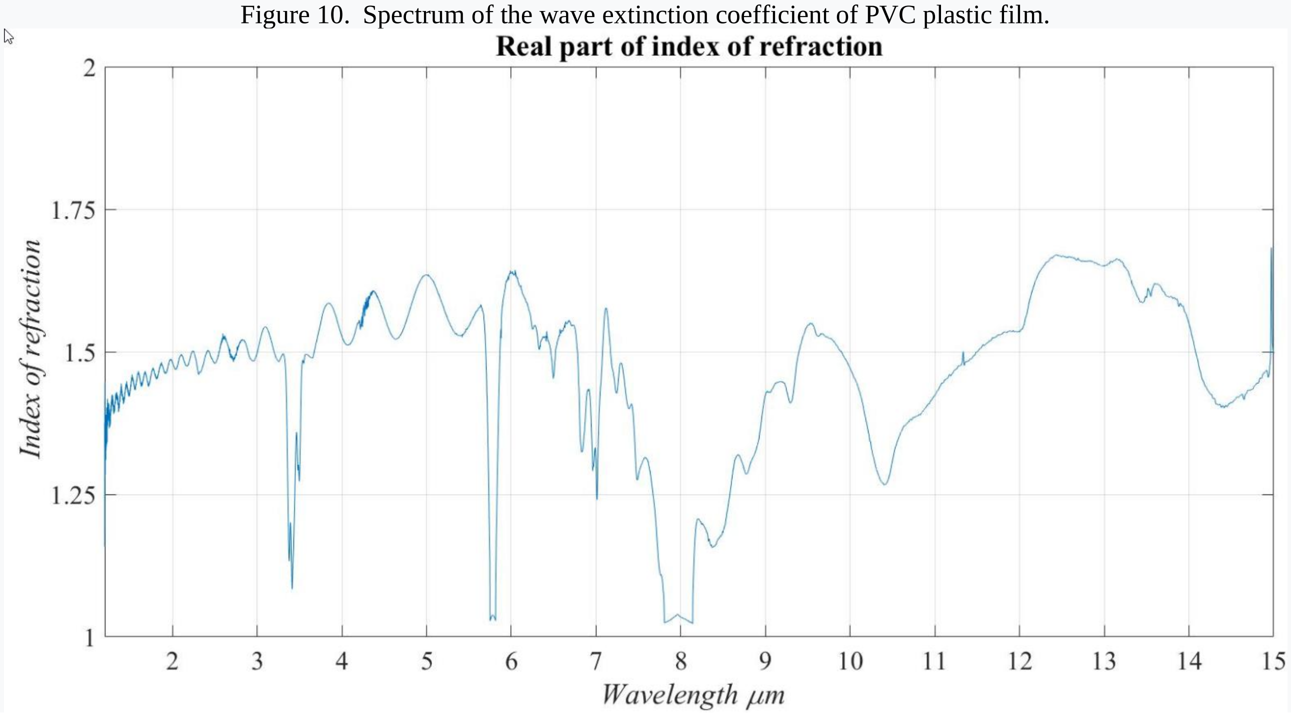


Figure 11. Real part of the plastic film's refractive index as a function of PVC wavelength.

Through the obtained graphics, the plastic film serves as a support medium for the analysis of absorptivity of electromagnetic radiation in the infrared band in materials in the form of grains, fibers, dust. The extinction coefficient denotes that radiation is poorly absorbed by the plastic film.

5. CONCLUSION

At first, it was specified whether PVC plastic films, for domestic use, could serve as a support for the analysis of radiative properties, powders, fibers and granules. Plastic film, in addition to being easy to handle, is an extremely cheap product, with little pollution and above all, easily found.

According to the first graphs presented by Fig. (6) and (7), it is clear to realize that the film is practically transparent for radiation between 1.2 and 7μm, practically 90% of all radiation crosses the film, it is also noteworthy that for radiation with wavelengths smaller than the thickness of the film, they are subject to wave interference, it is speculated that internal vibrations of electrical charges emit radiation at the same wavelength as the incident radiation.

The film also has a relatively low extinction coefficient of 0.02 for radiation with a wavelength less than 5µm, as seen in Fig. (10), which clearly shows that the material practically does not retain energy, and as expected the real part of the refractive index has an average value of 1.5. Therefore, given the duly presented conditions, it can be concluded that the plastic film is a suitable material for the analysis of granulates carried out by the equipment - Spectrometer 100 FT-IR & FT-NIR.

6. REFERENCES

Howell, J.R. and Mengüç, M.P. and Siegel, R., 2016, *Thermal Radiation Heat Transfer.* Boca Raton, Florida: CRR-PRESS

Kariper, I,A., 2017, "Optical and Structural Properties of Natural MnSeO4 Mineral Thin Film". *Materials Researchs.*Vol-20

Liang X. and Han, M., 2007, "Coherent thermal radiation in thin films and its application in the emissivity design of multilayer films", *Chinese Science Bulletin.*

Modest. F., 1993, *Radiative Heat Transfer.* New York, United States: McGraw-Hill.

Perkins Elmer Manual, < http://www.perkinelmer.com.br/brochuras/PerkinElmer%20Frontier.pdf>

Sadiku, N.O.M., 2014, *Elements of electromagnetism.* New York, United States: Oxford University Press.

Taleb, A.M. and Al-Wattar, A.J.H., 1998, "Design of windows to reduce solar radiation transmittance into buildings". *Solar & Wind Technology*. Pages 503-515.

Gertych A. P, Łapińska A., Czerniak-Łosiewicz K., Anna Dużyńska A., Zdrojek M. and Judek J., 2019, "Thermal properties of thin films made from MoS2 nanoflakes and probed via statistical optothermal Raman method". *Scientific Reports.*

Wozniak B. and Dera J., 2007, "Atmospheric and Oceanographic Sciences Library". New York: Springer

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.