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**Physical properties of some polymeric materials
and macromolecular materials of biomedical
interests**

Doctoral Thesis Summary

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Keywords: polymeric membranes, tacrolimus, poly(vinylalcohol), Raman spectroscopy, UV-VIS spectroscopy, gamma irradiation, UV irradiation.

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INTRODUCTION

During the evolution of human civilization, people have used different types of materials for various purposes. People have used natural polymers without realizing „nature” of their character, one of these natural polymer substances are natural rubber which comes from rubber tree known as *hevea brasiliensis*.

In the middle XIX century, chemists have synthesized polymer substances, but didn't have an understanding the molecular structure. In 1920, Staudinger showed that polymers are molecules containing basic units called „monomers”, based on covalent bonds. Soon the polymers synthesis has developed rapidly, especially during the years 1930-1960. Kuhn, Flory, Huggins, Stockmayer and others have developed theories that describe macromolecular size, volume effects, polymer solutions etc. Rouse and Zimm have developed theories for molecular dynamics.

Edwards, De Gennes, Cloizeaux and others have developed modern principles of polymer physics – polymer chain model and theory of solutions. Today, polymer physics includes a vast range of theoretical and experimental knowledge which is still unresolved.

Currently many pharmaceutical substances are composed by polymers (gels, membranes) used as support for active substances, the advantage of using of these polymers is the possibility to control the release of the active substances, applications and easy removal on the tissue, the tissue compatibility which they are applied.

In this stage we were interested of any changes of physical properties at macroscopic and microscopic scale of polymeric membranes under action of aggressive factors that can interfere with medical applications, prolonged contact with air or exposure to ultraviolet or gamma radiation. The action of these agents may be manifested by altering physical properties observable on a macroscopic scale (coefficient of absorption, color, physical consistency) or by affecting the molecular structure of chemical bonds or promote chemical reactions (oxidation reactions).

Preliminary studies were conducted to determine the most important category of agents with potential impacts on property degradation of these materials and to establish appropriate methods of investigation.

In the first part of the work are presented general theoretical aspects related to polymeric membranes.

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In the second chapter are describe the methods of investigation used in this study.

In the third chapetr describes the systems studied and the results obtained. The systems wich we were studied are tacrolimus and PVA membranes. These systems were irradiated with UV and gamma radiation and then investigated by methods Raman, UV-VIS, XRD and SEM.

This work ends with conclusions wich result from this study and the references.

POLYMERIC MEMBRANES

Membranes are submicron filter elements of pore size, which allows the separation of complex mixtures. Depending on pore size, the surface membranes can retain the particles in the suspension (microfiltration) and dissolved compounds (by ultrafiltration, nanofiltration, reverse osmosis).

Membranes are differentiated by the nature and type of material, structure and scope. Based on this classification criteria, the membranes are:

- a) *by nature of the material* – natural and synthetic;
- b) *by type of material* – polymer and inorganic;
- c) *by structure* – porous and dense;
- d) *by the scope* – microfiltration (MF), ultrafiltration (UF), nanofiltration (NF)

a) Nonporous membranes

Nonporous membranes or polymeric films were the first structure made for separation of liquid mixtures. Their structure is equated to the absence of microscopic pores with a range of molecular size pores, characterized by a structural porosity

b) Porous membranes

Porous membranes are composed of interconnected pores of molecular dimensions superior size, detectable by microscopic techniques.

c) Asymmetric membranes

Asymmetric membranes combine separation and permeability characteristics of porous and nonporous membranes. These membranes are distinguished by the porous surface layer, which is formed at the interface, in contact with air.

d) Composite membranes

Composite membrane is composed by a porous support obtained by inversion of phase and a ultrafine layer. This type of membranes is used in reverse osmosis, pervaporation and gas separation.

STUDIED SYSTEMS AND EXPERIMENTAL RESULTS

As preliminary studies, our attention was focused on commercial pharmaceutical systems whose properties were evaluated under UV and air actions. The systems studied contain the active substance tacrolimus and other ingredients, and it is known

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by commercial name protopic. The results of this study was the started of our study on PVA membranes.

1. TACROLIMUS

Tacrolimus (FK-506 or Fujimycin) is a medical active substance used for the treatment of atopic dermatitis, designed for direct application on the surface of the skin [1, 2]. Chemical formula is presented in figure 1.

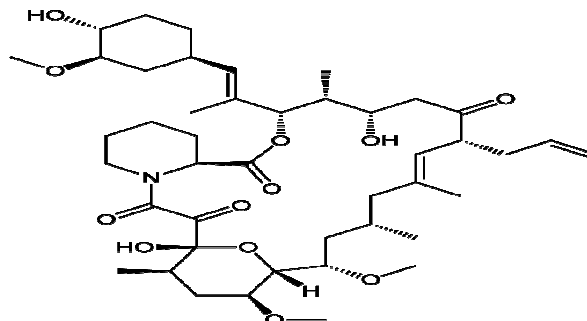


Fig. 1 Chemical formula of tacrolimus

Commercial form found tacrolimus is protopic which is available in two concentrations of active substance 0,1 % and 0,03 %. It also contain other ingredients: white soft paraffin, liquids paraffin, propylene carbonate, white wax. The product is presented as a relatively low-viscosity gel that allows easy display skin and then remove it after therapy.

Preliminary studies aimed the investigation of protopic with 0,1 % concentration tacrolimus. The aim of our work was to observe the behavior of this medical substance when submitted to a moderate period of time of air and UV exposure, with the possibility to enhance the UV absorption property by addition of TiO₂.

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1. 1 Effect of air exposure

The existence of new compounds like the oxides, are responsible for the apparition of new vibration bands in the spectrum. These new bands should be easily observed by comparison of the spectrum of the initial sample and the spectrum of the sample after air exposure. The spectra of the tacrolimus in initial state and after 3 hours of air exposure are presented in Fig. 2. The two spectra are very similar and contain the main vibration bands at the same wavelength. Some of these bands are: in the domain $300\text{-}400\text{ cm}^{-1}$ C-C aliphatic chain bend; $804\text{-}889\text{ cm}^{-1}$ domain C-O-C- rock; $1082\text{-}1300\text{ cm}^{-1}$ domain C-O stretch; $1381\text{-}1440\text{ cm}^{-1}$ C-H domain bend [5, 6]. However

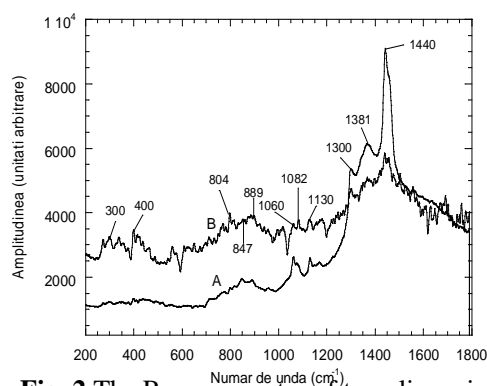


Fig. 2 The Raman spectra of tacrolimus in initial state (curve A), and after 3 hours air exposure (curve B)

the spectrum of non exposed sample is much smoother, and the vibration bands appears with a small amplitude in the domain $200\text{-}400\text{ cm}^{-1}$. This effect is determined by the dispersion effect of water contained in this sample. For the sample kept long time in contact with the air a small quantity of water evaporates, the dispersion effect is reduced and the structure of tacrolimus is not masked by water. The similarity between the two spectra indicates there is no modification of the molecular structure of tacrolimus after few hours of air exposure [6].

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1. 2 Effect of UV exposure

In the second stage of our work we tested the chemical stability of the tacrolimus under UV exposure. In medical applications the interval of time between two successive applications of the pharmaceutical product on the skin is 3-4 hours [3, 7].

a) UV VIS absorbtion

The diminution of the number of absorbents molecules results from the reduction of the area of the UV absorption spectra. This effect can be observed in figure 3. In the initial state (non irradiated), tacrolimus is characterized by a large spectrum with an important absorption coefficient in the domain 264 – 370 nm. The width of the spectrum designs a large distribution of the energetic states of absorbents molecules,

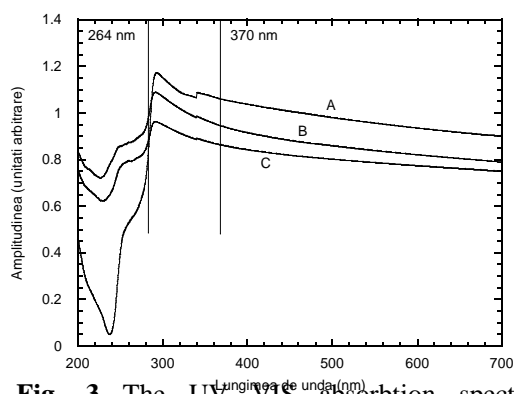


Fig. 3 The UV-VIS absorption spectra of tacrolimus in initial state and after different time intervals of UV irradiation: in initial state (curve A); after 2 hours irradiation (curve B); after 4 hours irradiation (curve C)

determined by rotation and vibration. A high absorption peak is observed at 293 nm and the spectrum is characterized by large area. After few hours of UV exposure, the amplitude of the peak diminishes, as well as the area under the graph. This behavior can be correlated with a reduction of the number of absorbent molecules. We suppose that a large number of molecules are subject of chemical degradation (possible oxidation), after long time UV irradiation. This effect is more evident when the time of exposure increases [8].

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b) Raman investigation

In order to observe possible modifications on the molecular scale induced by irradiation, we compared the Raman spectrum of the non irradiated sample with the

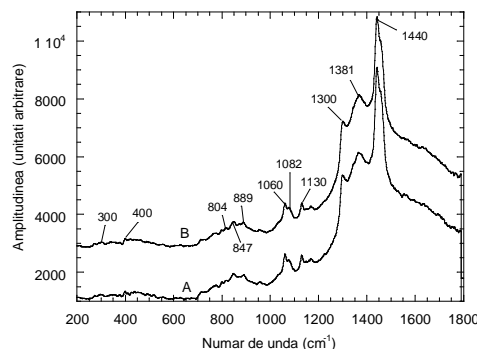


Fig. 4 The Raman spectra of non irradiated tacrolimus (curve A) and after 4 hours UV irradiation (curve B)

spectrum of the irradiated one. The spectra of the non irradiated sample and of the sample UV irradiated for 4 hours are very similar (fig. 4). The band at 1440 cm⁻¹ corresponding to C-H bend is more intense but in the domain 300-1000 cm⁻¹ the bands are less evidenced. This behavior demonstrates no modification of the chemical structure of tacrolimus [6].

1. 2 The effect of TiO₂

Titanium dioxide (TiO₂) is widely used to provide opacity of some UV VIS products such as paints, plastics, papers, inks, food and toothpaste. It is also used in cosmetics and skin care products and is present in almost any sun cream, to protect skin from ultraviolet light. It has very high capacity to absorb UV light and is known for proper compatibility with biological tissues at low concentrations [7, 9, 10].

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a) UV VIS absorbtion

After addition of TiO₂ in tacrolimus, the UV-VIS absorption spectra show the increase of the absorbance in the domain 250-350 nm with the increase of TiO₂

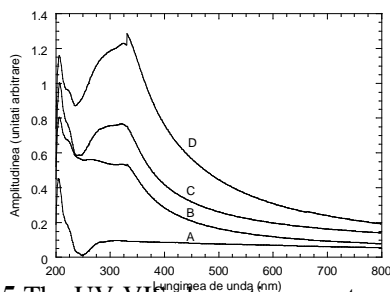


Fig. 5 The UV-VIS absorption spectra of samples: the tacrolimus in initial state (curve A), the tacrolimus with 3% of TiO₂ (curve B), the tacrolimus with 5% of TiO₂ (curve C) and the tacrolimus with 10% of TiO₂ (curve D)

concentration. If the maximum of absorbtion for tacrolimus in initial state is small, for tacrolimus dopped with 3%, 5% and 10% TiO₂ absorbtion increases. This observation is in accordance with other results reported in literature [11]. For medical applications an important conclusion results from this study, the UV absorbtion property can be enhanced by addition of TiO₂, but the chemical properties of the tacrolimus remains unchanged [6].

b) Raman investigation

The eventually interaction can be probed by comparing the Raman spectra of samples in initial state and after addition of TiO₂. These spectra are shown in Figure 6. The

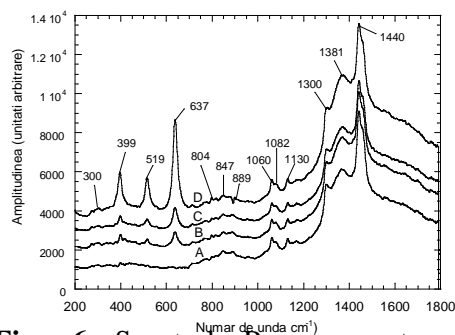


Fig. 6 Spectrul Raman pentru probele: tacrolimus în stare inițială (curba A), tacrolimus cu 3% TiO₂ (curba B), tacrolimus cu 5% TiO₂ (curba C), tacrolimus cu 10% TiO₂ (curba D)

characteristic vibration bands of tacrolimus appear clearly in all the spectra at the right

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wavenumber. In the domain 800 - 1500 cm^{-1} the difference between the spectra of samples with different TiO_2 concentrations are very small. The shape and the amplitude of the spectra didn't change and the vibration bands appear at the same wavenumber as for the sample without TiO_2 . Modifications can be observed in the domain 200 - 800 cm^{-1} . Supplementary bands appear at 399 cm^{-1} , 519 cm^{-1} and 637 cm^{-1} for the samples containing TiO_2 . As reported in literature, in the domain 200-800 cm^{-1} TiO_2 exhibits three vibration bands at 399, 519 and 637 cm^{-1} [12].

These observations demonstrate the fact that TiO_2 does not interact with tacrolimus and the chemical structure of both components is not modified. The system tacrolimus TiO_2 appears as a dispersion of TiO_2 in the matrices of tacrolimus.

Conclusions

The direct contact between the air and tacrolimus, at normal pressure and room temperature, for time intervals up to three hours don't affect the chemical structure of the active substance. This behavior is revealed by Raman spectroscopy. Similar behavior is observed after moderate UV exposure. The chemical structure is not modified. The absorption property is enhanced by the inclusion of TiO_2 in the tacrolimus matrix. Raman analysis indicates no chemical interaction between tacrolimus and TiO_2 . The system tacrolimus- TiO_2 remains stable even after few hours of UV exposure.

2. PVA membranes

Since its discovery in 1924 by W. O. Herrmann and W. Haechel, the Poly vinyl alcohol (PVA) is one of the most popular polymers with applications in different domains of activity, becoming with the industry, and finishing with the medicine [13, 14]. We can cite several such applications, e.g. in optics and photography it is used as a polarizing filter [15]. In medicine it is used as matrix for drug controlled release, in making artificial blood vessels, or contact lenses [16, 17]. The nanoparticles doped in polymer matrices have long stability, novel optical and electrical properties [18, 19]. Recently, in combination with other polymers and different doping materials, PVA was used to achieve direct conversion fuel cells [20]. Other promising applications are based on the acoustic-optical properties effects of PVA subsystem [21].

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Preparation of PVA membranes

The PVA used to prepare membranes has molecular weight of 20.000 – 30.000 and it is 88% hydrolyzed. Several types of samples, were prepared, undoped membranes, doped with TiO₂, doped with AgNPs and membranes subjected to the action of solvent (propanol). The PVA membranes undoped, doped with TiO₂ and doped with silver nanoparticles were analyzed in thiers original state and after UV irradiation at different intervals of time.

The undoped membranes were prepared as follows: the PVA powder was mixed with distilled water at constant temperature 55⁰ C during 3 hours until a homogeneous dispersion of polymer is obtained. Then the gel was displayed on a glass plate and kept 24 hours in dark, at room temperature, until all the water evaporates. We used PVA membranes with different polymeric concentrations, 15%, 20% and 30%.

The membranes doped with TiO₂ were prepared like the undoped, except that we add different concentrations of TiO₂ (1%, 10%, 20%), mixed the compounds several hours, then left to dry at room temperature for 24 hours.

The membranes doped with AgNPs were prepared like the undoped membranes, only that we added AgNPs and stir for one hour, and then we left to dry at room temperature for 24 hours.

Membranes immersed in solvent (propanol) were prepared as the undoped only after the gel was formed, it is spread over glass plates and then are immersed in propanol different times, 30 minutes, 60 minutes 90 minutes and 120 minutes. Then we left to dry at room temperature for 24 hours and then removed from the glass plates.

2.1. PVA membranes undoped

The effect of UV exposure PVA membranes

a) UV VIS absorbance

For ours study we used different concentrations of PVA membranes: 15%, 20% and 30%. These samples were analyzed in theirs original state and after UV irradiation at different intervals of time (1-4 hours).

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Figure 7 shows the absorption spectra for the sample with concentration 15% for different time exposure, from 1 hour to 4 hours. In the initial state, (un irradiated). The sample is characterized by a large spectrum with an important absorption peak in

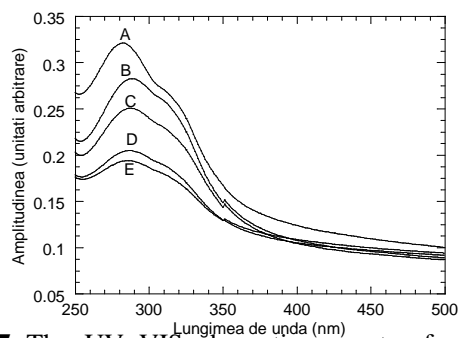


Fig. 7 The UV VIS absorption spectra for the sample with concentration 15% in initial state and after different time intervals of UV irradiation. A the sample in initial state; B after 1 hour irradiation; C after 2 hours irradiation; D after 3 hours irradiation; E after 4 hours irradiation

the domain 250-350 nm. The width of the spectrum suggests a large distribution of the energetic transitions, determined by rotation and vibration of molecules. For this sample the maximum absorption peak is observed at 282 nm. After 1 hour of UV exposure the amplitude of the peak decreases and shift slowly at 288 nm. Also the

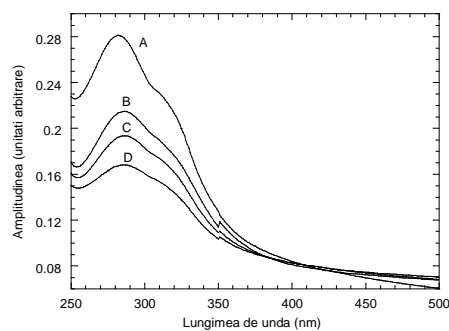


Fig. 8 Relaxation process of sample with concentration 15%. A the sample in initial state; B the sample after 4 hours irradiation UV and 4 weeks relaxation; C the sample after 4 hours irradiation UV and 3 weeks relaxation; D the sample after 4 hours irradiation UV

area under graphic decreases correspondly.

In the next stage of our work we investigated the behavior of absorption properties of these systems during the relaxation process. For this purpose, after the longest time of UV exposure, 4 hours, the samples were kept different time intervals, up to 3 weeks, in dark at room temperature, and the UV VIS absorption spectra were recorded at different intervals of time. During the relaxation process the absorption

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peak is observed at the same wavelength, but its amplitude increases monotonically with the time of relaxation (fig. 8).

b) Raman investigation

The Raman spectra give new information about the the structure of the sample. We did this analysis because we were interested to observe any changes induced by UV radiation. We compared the Raman spectrum of PVA membrane with concentration 20% in the initial state and after 4 hours of UV irradiation (fig. 9). It is observed that

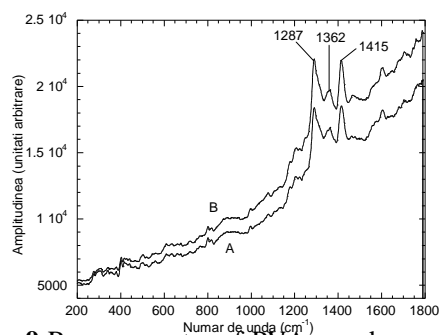


Fig. 9 Raman spectra of PVA membranes with 20% concentration in initial state and adter 4 hours of UV irradiation. A after 4 hours UV irradiation; B in initial state

the membrane in initial state contains well defined vibration bands in the domain 1200-1600 cm^{-1} . The most intense bands are assigned as follows: 1287 cm^{-1} – CH wagging, 1362 cm^{-1} – CH bending and OH bending, 1415 cm^{-1} – CH_2 bending [22, 23]. These bands appear also in the spectrum of membrane, after 4 hours irradiation, at the same wave number. It is observed that the increasing time of irradiation, decreases the amplitude bands. This fact indicates that in the PVA membranes appears the effect of photodegradation. [24]. Similar spectra are obtained for concentrations 15% and 30% after UV irradiation.

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c) X-ray diffraction

In figure 10 we compared the diffractograms of PVA in initial state and after 4 hours UV irradiation. It is observed that appears a maximum of diffraction at 29°

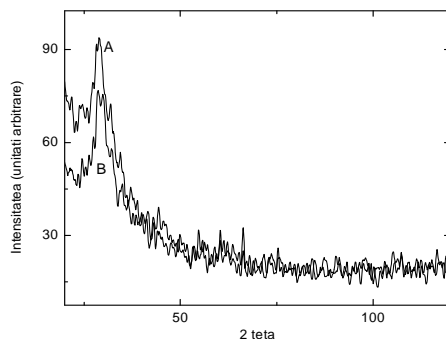


Fig. 10 X-ray diffractograms of PVA with 15% concentration. A in initial state; B after 4 hours UV irradiation

corresponding to plan (101) at crystalline phase [20, 25, 26, 27, 28]. After 4 hours UV irradiation, the intensity decreases and the crystalline phase remains. Appears a tendency of crystallize and coexistence the amorphous and crystalline phase.

These observations confirm the apparition of local order at UV exposure.

The effect of gamma irradiation of PVA membranes

a) UV VIS absorbance

The increase of the absorption coefficient at 280 nm after irradiation shows that some chromophores are formed. This can occur due to the scission of hydrogen and hydroxyl groups and the formation of carbonyl double bond (C=O) [29]. Thus the absorption band at 285 nm may be assigned to $\pi \rightarrow \pi^*$ transition of the carbonyl groups (Fig. 11) [30, 31]. For the sample with 20% PVA in initial state and after gamma irradiation at 739 Gy, 1478 Gy and 2217 Gy, it is observed that with increasing the time exposure, the absorption coefficient increases. There are no significant changes in the vibrational modes of the bands and the spectra have approximately the same form [32].

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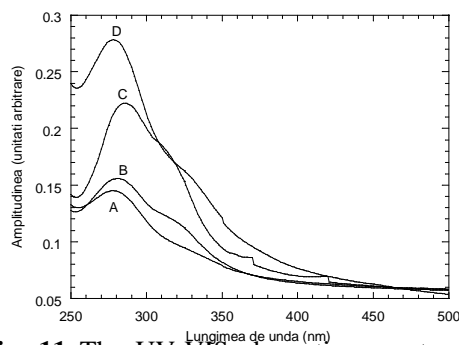


Fig. 11 The UV-VIS absorption spectra for the PVA membranes with 20% polymeric concentration irradiated at different doses: unirradiated (curve A), 739 Gy (curve B), 1478 Gy (curve C), 2200 Gy (curve D)

b) Raman investigation

The vibration bands appear at the same wavenumber as for the unirradiated samples, but the amplitude of the most intense bands increases with the dose of radiation. The increase of the intensity of vibration bands is determined by the increase of the number of chemical bonds involved in such vibration. Much more chemical bonds can vibrate when the molecules are free to move. The most intense bands and their assignment are as follows: 1288 cm^{-1} – δ (CH+OH) bending; 1355 cm^{-1} – CH_2 wagging and OH bending; 1412 cm^{-1} – CH and OH bending; 1600 cm^{-1} –

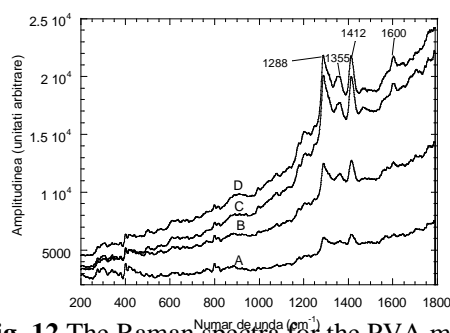


Fig. 12 The Raman spectra for the PVA membrane with 20% concentration, unirradiated and for different doses of γ radiation: unirradiated (curve A), 739 Gy (curve B), 2200 Gy (curve C)

$\text{C}=\text{C}$ stretching [21, 22]. As suggested previously, a possible effect of γ irradiation is the scission of the chains and breaking of hydrogen bonds having as consequence the increase of local dynamics of the polymeric chain. The fraction of short chains and of the free bending groups increases. However such structures exist before irradiation,

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only their ratio into the total mass of the sample could change. Even the breakings of hydrogen bond don't create any new structures different from those existing previously in the sample. In this case none new vibration states appear after irradiation, and none news vibration bands are expected to appear in the Raman spectrum. As bending groups, the vibration of OH and CH groups are the most affected by the packaging in long chains. The scission of the chains and the breakings of hydrogen bonds leads to the delivery of the bending groups from the constriction of packaging. We explain thus the increase of the intensity of the bands associated to these vibrations.

c) X-ray diffraction

A direct consequence of the breaking of hydrogen bonds and chain scission by γ radiation is the modification of local order of the chains with respect the modification of the crystallinity of the sample. Such possible changes may be

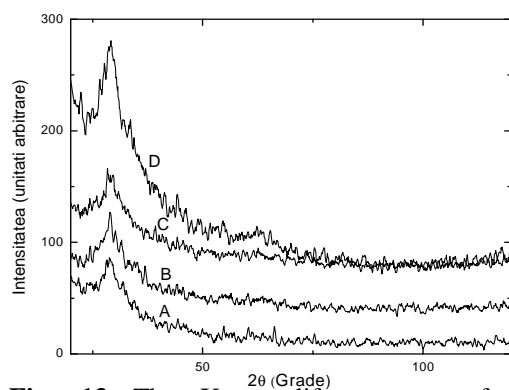


Fig. 13 The X-ray diffractograms for PVA membrane with polymeric concentration 15% (curve A), 20% (curve B), 30% (curve C) before γ irradiation, and 30% after γ irradiation at 2200 Gy (curve D)

investigated by XRD method, comparing the diffractograms of unirradiated and γ -irradiated membranes. The irradiation was carried out with a Co^{60} source.

Usually the polymeric membranes obtained from aqueous gels are characterized by amorphous structure, especially at low polymeric concentration. However, at high concentration of polymer in the initial aqueous gel, domains of local organization of the chains can occur, associated with the crystalline phase [33]. Such structures can be observed by X-rays diffraction. To verify these suppositions we recorded the diffractograms from the PVA membranes with different polymeric

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concentrations, before irradiations. The unirradiated samples with 15% polymeric concentration exhibit a typical peak at $2\theta=29^{\circ}$. This peak appears for all the concentrations and its amplitude remains almost constant, (in the limits of the noisy of the diffractograms), (Fig. 13). As reported in literature this peak is assigned to diffraction from the planes (101). In ours experiments the amplitude of this peak increases after irradiation (Fig. 13). This fact indicates that some changes on the local order of polymeric chains and possible crystallization appear after irradiation.

2. 2. PVA membranes doped with TiO₂

The effect of UV exposure of PVA membranes doped with TiO₂

a) UV VIS absorbance

We observed the absorption properties of polymeric membranes doped with different concentrations of TiO₂ in initial state and after different time intervals of UV

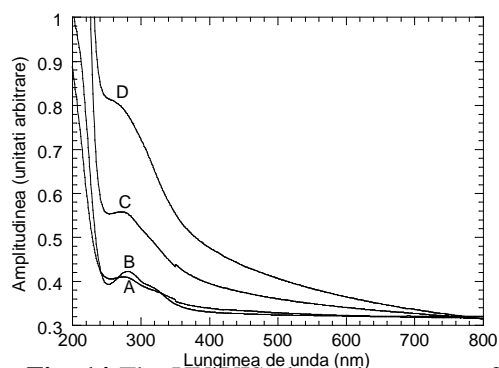


Fig. 14 The UV-VIS absorption spectra for the non doped membrane and membranes with different content of TiO₂, before irradiation. Curve A, the non doped membrane; Curve B, with 1% TiO₂; Curve C, with 10% TiO₂; Curve D, with 20% TiO₂

irradiation. At 1% concentration the absorption spectrum is very few modified. As the concentration of TiO₂ increases, the absorption peak is observed at the same wavelength but its amplitude increases continuously being few times greater than that of the non doped membrane, (Fig. 14) [34, 35]. This behaviour shows clearly the enhancement of absorption properties after addition of TiO₂. The doped membranes appear to be more stable under UV irradiation compared with the non doped ones.

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b) Investigarea Raman

In the next stage of our work we were interested to observe eventually interaction between the polymeric matrix and the TiO_2 , and eventually modifications on the molecular structure of doped and non doped membranes after UV exposure. To do this we compared the Raman spectra of membranes in initial state and after doping,

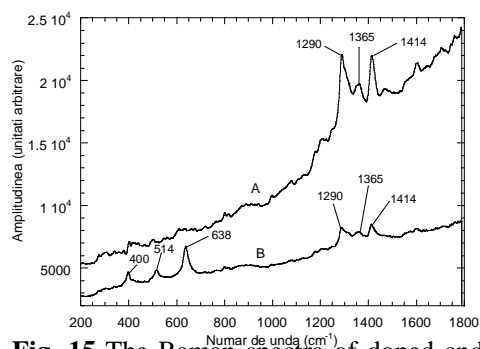


Fig. 15 The Raman spectra of doped and non doped membranes before irradiation. A the non doped membranes; B the membrane with 20% TiO_2 before irradiation

(Fig. 15). The spectrum of initial membrane contains well defined vibration bands in the domain $1200\text{-}1600\text{ cm}^{-1}$. The most intense bands are assigned as follows: 1290 cm^{-1} – CH wagging, 1365 cm^{-1} – CH- bending and OH – bending; 1414 cm^{-1} – CH_2 bending. These bands appear also in the spectrum of the doped membrane at the same wave number. Supplementary bands appear at 400 cm^{-1} , 514 cm^{-1} and 638 cm^{-1} for the samples containing TiO_2 . As reported in literature, in the domain $200\text{-}800\text{ cm}^{-1}$ TiO_2 exhibits three vibration bands at 400 , 514 and 638 cm^{-1} [34]. These bands appear in ours spectra at the right wave number, and theirs amplitudes increase with the concentration of TiO_2 . This effect clearly indicates the contribution of TiO_2 to the spectra. The fact that the vibration bands of PVA and TiO_2 appear at the same wave number before and after doping suggests no interaction between the polymeric matrix and the TiO_2 . The chemical structure of both components remains unchanged after doping.

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c) X-ray diffraction

Figure 16 shows the X-ray diffractograms of PVA-TiO₂ composite at different concentrations of TiO₂. The PVA membranes undoped have a crystalline property with a maximum of diffraction at $2\theta=29^{\circ}$. As shown in figure 16, TiO₂ is in anatase

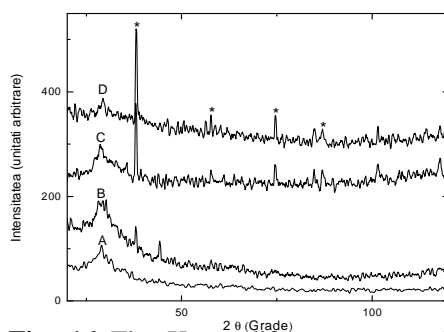


Fig. 16 The X-ray diffractograms for PVA membranes undoped and doped with TiO₂ in initial state: A undoped ; B with 1% TiO₂; C with 10% TiO₂ D with 20% TiO₂

form. The diffraction peaks are: $38,2^{\circ}$, $56,4^{\circ}$, $74,5^{\circ}$ și $86,4^{\circ}$ [20, 34, 36]. It is observed that the increasing of TiO₂ concentrations show a good diffraction peaks $2\theta=29^{\circ}$ and specific PVA decreases in intensity. The similar effect it observed for the PVA membranes irradiated UV.

The effect of gamma irradiation for PVA membranes doped with TiO₂

a) UV VIS absorbance

Figure 17 show the UV VIS absorbtion spectra for the sample with 20%

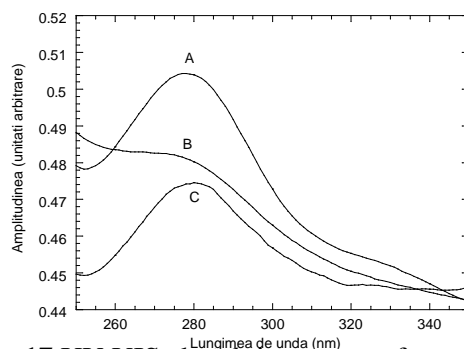


Fig. 17 UV VIS absorbtion spectra for membranes doped with different concentrations of TiO₂ after irradiation at 739 Gy. A with 1% TiO₂; B with 10% TiO₂; C with 20% TiO₂

polymeric concentration in which we added different concentrations of TiO₂ (1%,

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10%, 20%) after irradiation at 739 Gy. It is observed that the decrease of TiO_2 concentration leads to increasing the amplitude of the spectra. New peak of absorption appears at 280 nm. In the case of gamma irradiation, the amplitude increases with decreasing of TiO_2 .

b) Raman investigation

In figure 18 it is presented the Raman spectra of PVA membranes doped with 1%, 10%, 20% TiO_2 and irradiated at 2217 Gy. It is observed that the increasing of

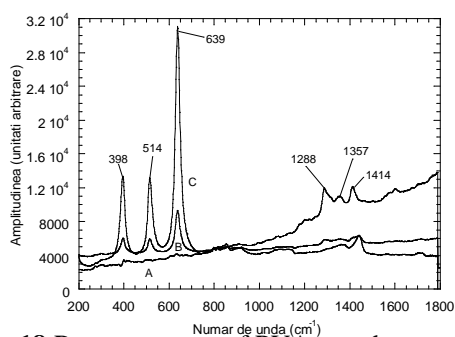


Fig. 18 Raman spectra of PVA membranes doped with different concentrations of TiO_2 after irradiation at 2217 Gy. A with 1% TiO_2 ; B with 10% TiO_2 ; C with 20% TiO_2

TiO_2 concentrations leads to the increase of the amplitude. The bands of PVA (1288 cm^{-1} , 1357 cm^{-1} and 1414 cm^{-1}) and the bands of TiO_2 (398 cm^{-1} , 514 cm^{-1} and 639 cm^{-1}) appears at the same wavenumber like in the case of PVA membranes in initial state.

c) X-ray diffraction

In figure 18 are shown the X-ray diffractograms for PVA este prezentat membranes

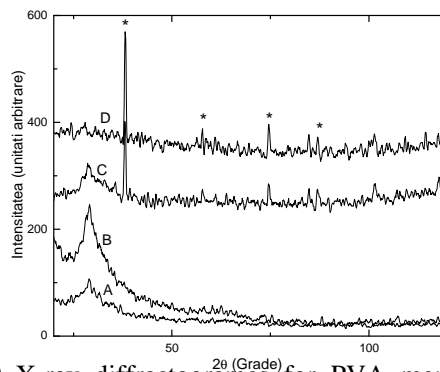


Fig. 19 X-ray diffractograms for PVA membranes doped and undoped in initial state and after gamma: A undoped and unirradiated ; B undoped and irradiated gamma; C with 20% TiO_2 unirradiated; D with 20% TiO_2 irradiated gamma

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undoped and doped in initial state and after gamma irradiated at 4400 Gy. We can identify the peaks diffraction for PVA at $2\theta=29^{\circ}$ and for TiO_2 at $38,2^{\circ}$, $56,4^{\circ}$, $74,5^{\circ}$ și $86,4^{\circ}$ [20, 34, 36]. For PVA membranes doped with TiO_2 , the intensity didn't change.

2. 3 PVA membranes doped with AgNPs

The effect of UV exposure for PVA membranes doped with AgNPs

a) UV VIS absorbance

In figure 20 it is present the UV VIS absorption spectrum for PVA membranes in initial state and doped with 0.04 ml AgNPs after 4 hours UV exposure. Supplementary band, centred at 450 nm, appears in this spectrum. As reported in

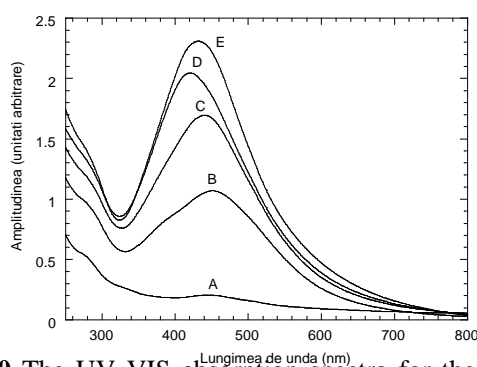


Fig. 20 The UV VIS absorption spectra for the doped sample before and after different time intervals of UV irradiation. A). the sample before irradiation; B). the sample after 1 hour irradiation; C). the sample after 2 hours irradiation; D). the sample after 3 hours irradiation; E). the sample after 4 hours irradiation

literature, this band is assigned to plasmonic resonance frequency of silver nanoparticles [37]. The main characteristics of the spectrum, respectively the absorption bands at 275 and 450 nm appear in all spectra but some differences can be observed in function of dose of radiation. The absorption peak at 450 nm were found to be blue shifted as the time of UV irradiation increases. After 4 hours of irradiation the absorption peak shifts to 432 nm. UV irradiation facilitates the rearrangement of local chains and the migration of isolated Ag^+ ions existing in the system. By self assembled mechanism such ions can give rise to new nanoparticles with different size compared to those existing initially in the system [38].

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b) X-ray diffraction

In figure 21 we were compared the X-ray diffractograms for PVA membranes undoped and doped with AgNPs, irradiated 4 UV. It is observed that the peak of PVA

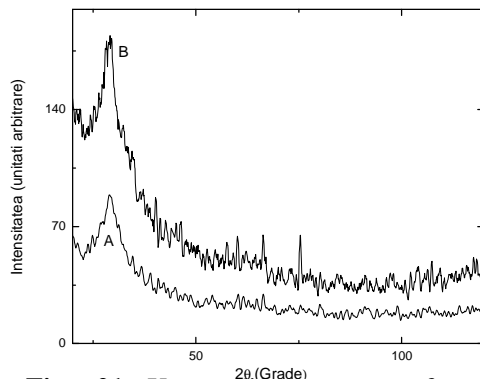


Fig. 21 X-ray diffractograms for PVA membranes irradiated 4 hours UV: A undoped; B doped with AgNPs

membranes doped with AgNPs has increasing and it appears new peaks characterized by AgNPs.

It is observed that after 4 hours of UV exposure, the intensities decreases slowly. The PVA diffracton peak appears at $2\theta = 29^\circ$, the diffracton peaks for AgNPs appear at: $57,4^\circ$, $66,3^\circ$, $95,6^\circ$ and correspond to plans (111), (200) and (220) [39, 40, 41].

The effect of gamma irradiation for PVA membranes doped with AgNPs

a) UV VIS absorbtion

Figure 22 shows the spectrum of doped membrane before irradiation and the spectra for different gamma doses (729 Gy, 1478 Gy and 2217 Gy). It can be seen a

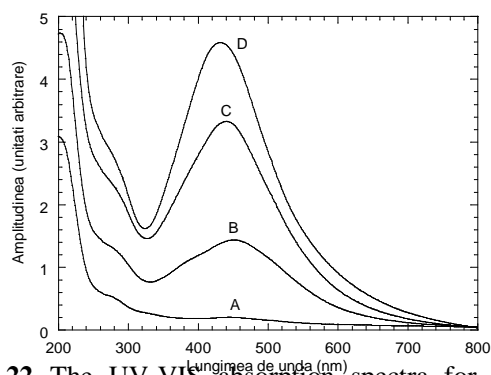


Fig. 22 The UV-VIS absorption spectra for doped samples irradiated at different gamma doses. A). the sample before irradiation; B). after gamma radiation dose at 739 Gy; C). after gamma radiation dose at 1478 Gy; D). after gamma radiation dose at 2217 Gy

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nearly zero absorption in the wavelength range 300-800 nm followed by a continuous increase in the absorption in the wavelength range 200-300 nm. A very small absorption peak appears at 450 nm. It is observed that the amplitude of the 450 nm peaks is increasing from 1.5 a.u at 739 Gy to 3.3 a.u at 1478 Gy and 4.6 a.u for the radiation dose at 2217 Gy).

2.4 The effect of solvent on PVA membranes

The asymmetric membranes were prepared for the first time by Loeb and Sourirajan [45] and it makes important progress in this study, special the separation properties [46]. An asymmetric membrane is characterized by a thin layer, under which is a solid porous matrix.

As being a material with a good chemical stability, thermal and a increase

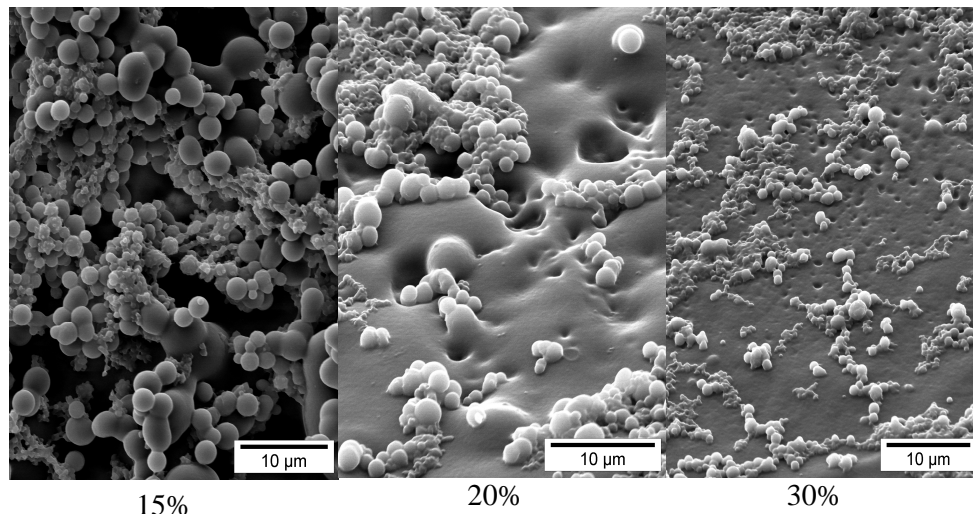


Fig. 25 Comparison of different concentration of PVA, 90 minutes immersion in propanol

permeability, PVA is a good material to obtain membranes [47].

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Conclusions

The effect of moderate UV exposure on the absorption properties of PVA was observed by UV spectroscopy. The amplitude of the absorption peak of PVA diminishes continuously with the time of UV exposure. This effect indicates a modification of local order of polymeric chains, eventually an effect of crystallization induced by radiation. Similar effect was observed for samples with high polymeric concentration, but the variation of the amplitude of the absorption peak is less important compared with the samples with small concentration. This behavior can be correlated with the dynamics of polymeric chains, which is more reduced at high concentration. An effect of relaxation is observed for all the samples after the UV exposure is stopped. The amplitude of absorption peak increases with the duration of relaxation and the systems evolve towards its initial state before the exposure. This effect is determined by the destruction of local order after the irradiation was stopped. This reversible process indicates no stable modification of the structure of the system at these doses of UV radiation.

The UV-VIS absorbance of PVA-TiO₂ membranes, before irradiation increases continuously with the concentration of polymer. After γ irradiation the UV-VIS absorbance of pure PVA membrane increases. This behavior is determined by the breaking of the polymeric chain and apparition of new water molecules. At low TiO₂ concentration (i.e. 1%) we observe similar behavior. As concentration of TiO₂ increases, i.e. 10% and 20%, the absorbance after γ irradiation decreases. Two mechanisms explain this behavior, the strong absorption of γ radiation by TiO₂ nanoparticles with effect the reduction of γ flux interacting with the polymeric chain, and second, the evaporation of residual water trapped in the polymeric matrix under γ irradiation. At high concentrations of TiO₂ the evaporation exceeds the apparition of new water molecules from the breaking of the polymeric chains that explains the important reduction of the UV absorbance of these samples after γ irradiation.

The X-ray diffractograms of unirradiated samples show a weak degree of local organization of the chains. The characteristic XRD peak of PVA increases after γ irradiation. We associated this behavior with the increase of fraction of local order of samples.

The effect of UV radiation and gamma irradiation on the properties of PVA with AgNPs was observed by UV VIS spectroscopy. Compared with the spectrum of pure polymer, a supplementary absorption peak appears at 450 nm, attributed at

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AgNPs. The amplitude of the 450 nm absorption peak of doped membranes is increasing continuously with the time of UV exposure. Similar behaviour was observed after gamma irradiation, but the absorption effect is enhanced. This behaviour is associated with the spontaneous formation of silver nanoparticles or scission of agglomeration of such systems.

The effect of UV radiation on the properties of PVA was observed by UV VIS and Raman spectroscopy. The amplitude of the absorption peak of PVA diminishes continuously with the time of UV exposure. This effect suggests an effect of crystallization induced by irradiation. The absorption property of PVA is enhanced by addition of TiO₂. The absorption coefficient increases with the concentration of dopant. The absorption properties of doped membranes are very few affected by UV irradiation. This fact demonstrates the stabilization effect of TiO₂ on the absorption property. Raman analyze of doped and non doped membranes indicates no modification of chemical structure after UV exposure.

The morphology of membranes is change with the increasing of immersion time in propanol, from a uniform structure to at an asymmetrical structure.

Selective bibliography:

1. J. J. Russell, *Topical Tacrolimus: A new therapy for atopic dermatitis*, American Family Physician 15, 1899 (2002)
2. C. Pascual, A. B. Fleischer, *Tacrolimus ointment (protopic) for atopic dermatitis*, Skin Therapy Letter 9, 9, 1 (2004)
3. D. W. Clegg, A. A. Collyer, *Irradiation effects on polymers*, Springer, New York (1991)
4. A. Kelen, S. Balint, A. Bodis, L. Toth, HU P0600097, 1 March 2007, World Intellectual Property Organization (WIPO) Geneva, Switzerland
5. J. Y. Horiba, Raman Data and Analysis, Raman Application Note
6. M. Todica, L. Udrescu, *Preliminary spectroscopic investigation of tacrolimus TiO₂ system*, Cent. Eur. J. Phys, Vol. 9, No. 6, pg. 1536-1539 (2011) DOI: 10.2478/s11534-011-0075-7
7. G. Thilo, S. T. Nordwig, M. Georg, H. Julia, D. Heinrich, A. Peter, K. Alexander, *Topical tacrolimus neither prevents nor abolishes ultraviolet - induced erythema*, Journal of the American of Dermatology 55, 5, 882 (2006)
8. L. Udrescu, M. Pop, V. Balc, M. Todica, *Observation of the effects of UV exposure of some samples containing tacrolimus*, Studia UBB Physica, LV, 2 (2010)
9. H. Ruixia, W. Leigang, W. Jin, H. Nan, *Investigation on biological properties of tacrolimus – loaded poly(1,3-trimethylene carbonate) in vitro*, Applied Surface Science 256, 5000 (2010)
10. R. Yanagisawa, H. Takano, K. Inoue, E. Koike, T. Kamachi, K. Sadakane, T. Ichinose, *Titanium dioxide nanoparticles aggravate atopic dermatitis – like skin lesions in NC/NGA mice*, Experimental Biology and Medicine 234, 314 (2009)

Physical properties of some polymeric materials and macromolecular materials of biomedical interests

11. J. Zhang, M. Li, Z. Feng, J. Chen, C. Li, *UV Raman spectroscopic study on TiO₂. I. Phase transformation at the surface in the bulk*, J. Phys. Chem. B 110, 927 (2006)
12. H. C. Choi, Y. M. Jung, S. B. Kim, *Size effects in the Raman spectra of TiO₂ nanoparticles*, Vibrational Spectroscopy 37, 33 (2005)
13. D. Lopez, I. Cendoya, F. Torres, J. Tejada, C. Mijanagos, *Preparation and characterization of poly(vinyl alcohol)-based magnetic nanocomposites. I. Thermal and mechanical properties*, Appl. Polym., 82, 3215 (2001)
14. Y. Badr, K. M. Abd El-Kader, R. M. Khafagy, *Raman spectroscopic study of CdS, PVA composite films*, J. Appli. Poly, 92, 1984 (2004)
15. C. A. Finch, *Poliviny alcohol properties and applications*, Wiley, New York, 508 (1973)
16. S. Horike, S. Matsuzawa, K. Yamaura, *Preparation of chemically crosslinked gels with maleate-denatured poly(vinylalcohol) and its applications to drug release*, J. Appl. Polymer, 84, 1178 (2002)
17. I. Kaetsu, *Drug Delivery system*, CMC, Tokyo (1986)
18. D. Y. Godovsky, *Electron behavior and magnetic properties of polymer nanocomposites*, Adv. Polymer, 119, 79 (1995)
19. L. L. Beecroft, C. K. Ober, *Advanced Nanocomposite Materials for Optical Applications*, Chem. Mater, 9, 1302 (1997)
20. C. C. Yang, *Synthesis and characterization of the cross – linked PVA/TiO₂ composite polymer membrane for alkaline DMFC*, Journal of Membrane Science, 288, 51 (2007)
21. Y. Badr, M. A. Mahmoud, *Manifestation of the silver nanoparticles incorporated into the poly vinyl alcohol matrices*, J Mater. Sci 41, 3947 (2006)
22. I. Omkaram, R. P. Sreekanth, J. Lakshmana Rao, *EPR, optical, infrared and Raman studies of VO²⁺ ions in polyvinylalcohol films*, Physica B, 388, 318 (2007)
23. P. S. Thomas, B. H. Stuart, *A Fourier transform Raman spectroscopy study of water sorption by poly(vinyl alcohol)*, Spectrochimica Acta Part A, 53, 2275 (1997)
24. H. Kaczmarek, A. Podgorski, *The effect of UV - irradiation on poly(vinyl alcohol) composites with montmorillonite*, Journal of Photochemistry and Photobiology A: Chemistry, 191, 209 (2007)
25. G. Gnana Kumar, P. Uthirakumar, K. S. Nahm, R. Nimma Elizabeth, *Fabrication and electro chemical properties of poly vinyl alcohol/para toluene sulfonic acid membranes for the applications of DMFC*, Solid State Ionics, 180, 282 (2009)
26. S. Rajendran, M. Sivakumar, R. Subadevi, M. Nirmala, *Characterization of PVA–PVdF based solid polymer blend electrolytes*, Physica B, 348, 73 (2004)
27. G. Nasar, M. Saleem Khan, U. Khalil, *Structural study of PVA composites with inorganic salts*, J Pak Mater Soc, 3, 67 (2009)
28. Y. Wang, Y. L. Hsieh, *Crosslinking of Polyvinyl Alcohol (PVA) Fibrous Membranes with Glutaraldehyde and PEG Diacylchloride*, Journal of Applied Polymer Science, 116, 3249 (2010)
29. N. V. Bhat, M. M. Nate, M. B. Kurup, V. A. Bambole, S. Sabharwal, *Effect of γ -radiation on the structure and morphology of polyvinyl alcohol films*, Nuclear Instruments and Methods in Physics Research B, 237, 585 (2005)
30. R. F. Bhajantri, V. Ravindrachary, A. Harisha, V. Crasta, P. Nayak, B. Poojary, *Microstructural studies on BaCl₂ doped poly(vinyl alcohol)*, Polymer, 47, 3591 (2006)
31. V. Svorcik, K. Proskova, V. Rybka, J. Vacik, V. Hnatowicz, Y. Kobayashi, *Changes of PEEK surface chemistry by ion irradiation*, Mater. Lett, 36, 128 (1998)

Physical properties of some polymeric materials and macromolecular materials of biomedical interests

32. S. G. Abd Alla, H. M. Said, A. W. El-Naggar, *Structural properties of γ -irradiated poly(vinyl alcohol)/poly(ethylene glycol) polymer blends*, Journal of Applied Polymer Science, 94, 167 (2004)
33. J. P. Cohen Addad, *Physical properties of polymeric gels*, John Wiley & Sons, Chichester (1996)
34. S. Mallakpour, A. Barati, *Efficient preparation of hybrid nanocomposite coatings based on poly(vinyl alcohol) and silane coupling agent modified TiO₂ nanoparticles*, Progress in Organic Coatings, 71, 391 (2011)
35. J. Zhang, M. Li, Z. Feng, J. Chen, C. Li, *UV Raman spectroscopic study on TiO₂. I. Phase transformation at the surface in the bulk*, J. Phys. Chem. B 110, 927 (2006)
36. N. T. B. Linh, K. H. Lee, B. T. Lee, *Fabrication of photocatalytic PVA - TiO₂ nano-fibrous hybrid membrane using the electro-spinning method*, J. Mater. Sci, 46, 5615 (2011)
37. Y. Badr, M. A. Mahmoud, *Enhancement of the optical properties of poly vinyl alcohol by doping with silver nanoparticles*, Journal of Applied Polymer Science, 99, 3608 (2006)
38. L. Udrescu, B. Marta, M. Pop, C. V. Pop, T. Stefan, M. Todica, *Observation of UV-VIS absorption properties of some PVA membranes with silver nanoparticles*, Studia UBB Chemia, 56 (LVI), 179 (2011)
39. A. Krkljes, M. Marinovic-Cincovic, Z. Kacarevic-Popovic, J. Nedeljkovic, *Radiolytic synthesis and characterization of Ag-PVA nanocomposites*, European Polymer Journal, 43, 2171 (2007)
40. S. Mandal, S. Arumugam, R. Pasricha, M. Sastry, *Silver nanoparticles of variable morphology synthesized in aqueous forms as novel templates*, Bull. Mater. Sci, 28, 503 (2005)
41. B. Raneesh, A. Pragatheeswaran, P. Dhanasekaran, P. Chandrasekaran, N. Kalarikkal, *Synthesis and characterization of silver-polyvinyl alcohol and plasma effect*, Journal of Ovonic Research, 6, 187 (2010)
42. W. H. Eisa, Y. K. Abdel-Moneam, Y. Shaaban, A. A. Abdel-Fattah, A. M. Abou Zeid, *Gamma – irradiation assisted seeded growth of Ag nanoparticles within PVA matrix*, Materials Chemistry and Physics, 128, 109 (2011)
42. J. L. Endrino, R. Escobar Galindo, H. S. Zhang, M. Allen, R. Gago, A. Espinosa, A. Anders, *Structure and properties of silver-containing α -C(H) films deposited by plasma immersion ion implantation*, Surface and Coatings Technology, 202, 3675 (2008)
44. D. H. Williams, I. Fleming, *Spectroscopic methods in organic chemicals*, McGraw-Hill (1995)
45. S. Loeb, S. Sourirajan, *Sea water demineralization by means of an osmotic membrane*, Adv. Chem, Ser, 38, 117 (1963)
46. M. Mulder, *Basic principles of membrane technology*, Kluwer, Dordrecht, The Netherlands (1991)
47. I. Sakurada, *Polyvinyl alcohol fibers*, New York, Marcel Dekker (1985)

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