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Fabrication and Characterization of PVA–PEG–SiO_2–NiO Nanocomposites for Modern Applications

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The purpose of this work is to create new nanocomposite films using polyvinyl alcohol (PVA) and polyethylene glycol (PEG) with nanostructures of silicon dioxide (SiO_2) and nickel oxide (NiO) for use in challenges involving gamma-rays as shields. The nanocomposites indicate favourable characteristics for gamma ray shielding, including lightweight, good flexibility, large attenuation coefficients, and cost-efficiency. The structural properties and surface morphological changes of the nanocomposite are analysed using an optical microscope. Scanning electron microscopy displays multiple coherent and consistently dispersed, randomly scattered clusters or pieces. The created nanocomposites are evaluated to see how well they can block gamma-radiation. According to the experimental results, the PVA–PEG–SiO_2–NiO-nanocomposite films reveal substantial attenuation coefficients, when subjected to gamma rays. This nanocomposite has potential as a material for gamma-ray shielding and elastic uses.

Метою цієї роботи є створення нових нанокомпозитних плівок з використанням полівінілового спирту (ПВС) та поліетиленгліколю (ПЕГ) з наноструктурами діоксиду Силіцію (SiO_2) та оксиду Ніклю (NiO) для використання в завданнях, пов'язаних з гама-променюванням, як екрани. Нанокомпозити демонструють сприятливі характеристики для екранування гама-випромінення, включаючи легку вагу, добру гнучкість, великі коефіцієнти ослаблення й економічну ефективність. Структурні властивості та морфологічні зміни поверхні нанокомпозиту було проаналізовано за допомогою оптичного мікроскопа. Сканувальна електронна мікроскопія показує численні когерентні та послідовно розподілені, хаотично розкидані кластери або фраґменти. Створені нанокомпозити було оцінено, щоб побачити, наскільки добре вони можуть

блокувати гама-випромінення. Згідно з експериментальними результатами, нанокомпозитні плівки ПВС–ПЕГ–SiO_2–NiO демонструють значні коефіцієнти ослаблення гама-променів. Цей нанокомпозит має потенціал як матеріял для екранування гама-випромінення та використання в еластичних матеріялах.

Key words: PVA/PEG nanocomposites, SiO_2–NiO nanoparticles, scanning electron microscopy, gamma rays.

Ключові слова: нанокомпозити PVA/PEG, наночастинки SiO_2–NiO, сканувальна електронна мікроскопія, гама-променювання.

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1. INTRODUCTION

Nowadays, polymeric materials are among the most widely utilized materials because of their low cost, simplicity of production, good norms, and frequent excellent performance. It is well known that the majority of polymeric materials are insulators and that the electrical and electronic industries have long used these materials. Polymeric materials have long been utilized as an auxiliary material, but due to their advantageous properties, they are now considered a fundamental material for usage in the electrical and electronic sectors [1, 2].

A polymer mixture is created by combining two or more polymers to form a novel material with different physical characteristics. There are five main types of polymer blends, including thermoplastics, thermosetting blends. A lot of interest has been focused on polymer mixing as a simple and affordable method of producing scalable polymeric materials for industrial use [3]. Put another way, the characteristics of the mixes may be adjusted based on their intended use by carefully selecting the polymer materials [4, 5].

One kind of material with special qualities is called a polymer nanocomposite (PNC). When nanoparticles or nanofillers are dispersed throughout a polymer matrix, the result is a polymer nanocomposite (PNC). To enhance the material's high-quality qualities, at least one dimension of an organic polymer matrix is filled with metallic particles [6, 7]. Modern polymers called PNCs can be utilized in place of more conventional packed polymers. Among these attributes are the greatly improved characteristics of nanocomposites due to their filler dispersion in comparison to pure polymers. Heightened conductivity, thermal stability, and tensile strength combined with decreased flammability. Additionally, the addition of nanoparticles to polymer composites produced a new class of composite materials with enhanced and distinctive characteristics. Exam-

ples of these are spheroids, fibres, and platelets [8, 9].

Polyvinyl alcohol, or PVA, is a polymer that exhibits remarkable qualities, including its capacity to produce hydrogels by chemical or physical means, as well as its non-toxicity, biocompatibility, water solubility, and non-carcinogenic nature [10, 11]. PVA is suitably flexible and has a high sufficient tensile strength. Ranges of low molecular chemicals, the majority of which include polar groups, are often used to plasticize PVA in order to increase its deformability [12, 13]. Another manmade polymer that is dissolved in water and has a wide molecular weight band is polyethylene glycol (PEG). Because of its elastic chain, combining it with rigid polymers to generate new materials with certain properties is a good alternative [14, 15]. Polyethylene glycol (PEG) is a polyether molecule that is used in a variety of scientific sectors and businesses because of its unique physicochemical properties [16].

Silicon oxide (SiO_2) or silica is a most common in nature as quartz. It has many forms, but all forms of silica are identical in chemical composition, but with different atomic arrangements. All forms of silica are odourless solids composed of silicon and oxygen atoms [17]. Among its many exceptional qualities are low expansion factor, rigidity, and thermal stability. Nanosilica is also known as nano-silicon dioxide (SiO_2). Researchers from all around the world are interested in composites made of silicon dioxide at the nanoscale [18, 19]. Among the many nanomaterials, which are accessible, nickel oxide (NiO) nanoparticles have attracted a lot of interest primarily due to their exceptional stability and superior optical, electrical, magnetic, and catalytic characteristics. Their numerous uses, such as in gas detectors, electrochromic parts, rechargeable batteries, dye-sensitive solar cells, solar energy absorbers, and magnetic cameras [20, 21].

NiO nanoparticles (NPs) are essential for preserving the quality of the environment because they can efficiently remove both organic and inorganic contaminants [22]. The potential harm that gamma rays can do to human health makes the study of shielding against gamma radiation an exciting field of research. To block γ-rays, varieties of materials were used, such as glass and concrete. Recycled thermoplastics and inorganic nanofillers were combined to create nanocomposites with the desired γ-radiation and x-ray attenuation capabilities [23]. With the growing use of radioactive materials in industry and medicine, shielding is essential to safeguarding people and equipment [24].

2. MATERIALS AND METHODS

In order to make a more homogeneous solution, PVA/PEG was com-

bined in 45 mL of distilled water using a magnetic stirrer at 70°C for 50 minutes. This process produced nanocomposites. The casting procedure was utilized to generate films of nanocomposites with different weight percentages 0, 2, 4, 6, and 8 wt.% of silicon dioxide (SiO_2)–nickel oxide (NiO) NPs. The homogeneous solution was placed in a petri dish and left to dry for 6 days at room temperature. It was then extracted and cut into parts. The following measurements were performed on the resulting PVA–PEG–SiO_2–NiO nanocomposites: A 20× magnification Olympus system Nikon-73346 optical microscope equipped with a microscopic photographic camera was employed. The structural features of nanocomposites were investigated using field emission scanning electron microscopy (FE–SEM) (Model/Inspect TM F50-DETAILS ≅ 1.2 nm at 10 kV; pressure 3.11e-3 par; country—Holland). PVA–PEG–SiO_2–NiO nanocomposites under study were used to attenuate gamma rays for different concentrations of SiO_2–NiO nanoparticles with different volume fractions, applying nanocomposites as a gamma-ray shield .The samples were placed parallel in front of a gamma-ray source Cs-137.5 mci, at a distance of 3 cm. Utilizing Geiger counter measurements of transmitted gamma ray fluxes *via* PVA–PEG–SiO_2–NiO NCs nanocomposites, the linear attenuation coefficients were computed.

Based on the thicknesses of the films, the linear attenuation coefficients (μ) may be obtained using the following equation [25, 26]:

$$N = N_0 e^{-\mu x}. \quad (1)$$

Here, μ—the attenuation coefficient of gamma radiation, and the number of radiation particles, designated as N_0, measured during a certain time frame in the absence of an absorber. Furthermore, when a sample of thickness x is added, the research looks at the number of particles, N, found throughout the same time period.

3. RESULTS AND DISCUSSIONS

3.1. Optical Microscopy for PVA–PEG–SiO_2–NiO NCs

Photographs of PVA–PEG–SiO_2–NiO nanocomposites taken at a power of 20×magnification are displayed cross-sectionally in Fig. 1. A clear distinction is made between SiO_2–NiO nanoparticles and PVA–PEG mixture in nanocomposites. The clearly visible interconnected network of SiO_2–NiO nanoparticles forming paths connected to each other within the nanocomposite samples resembles sponge bonding. It indicates that the nanoparticles spread in the matrix of the polymer mixture in a regular manner in all directions, filling

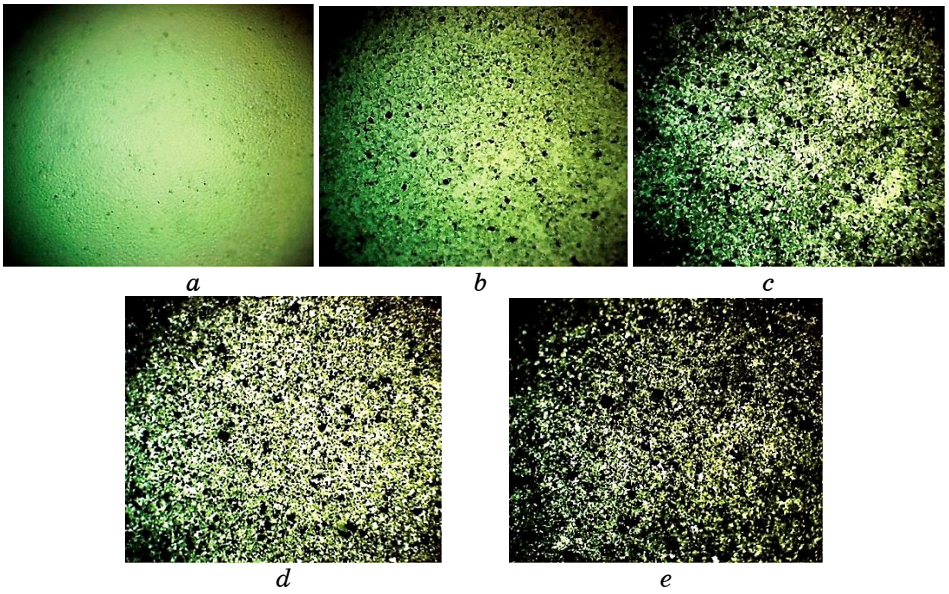

Fig. 1. Photomicrographs ×20 for PVA–PEG–SiO_2–NiO NCs: *a*—for pure PVA–PEG; *b*—for 2 wt.% SiO_2/NiO; *c*—for 4 wt.% SiO_2/NiO; *d*—for 6 wt.% SiO_2/NiO; *e*—for 8 wt.% SiO_2/NiO.

all the voids inside the polymer. Based on the microscopic images in Fig. 1, the proportions of the nanoparticles can be distinguished. The continuous network in the shapes *b*, *c*, *d*, and *e* increases the movement of charge carriers, and thus changes the properties of the nanocomposite [27, 28].

3.2. Scanning Electron Microscopy (SEM) Measurements of PVA–PEG–SiO_2–NiO NCs

A scanning electron microscope is used to look at the distribution of nanocomposites particles in the matrix of polymers and to assess the overall effect of the quantity of SiO_2/NiO NPs. A SEM image of the pure blend surface for films composed of PVA–PEG–SiO_2–NiO NCs is shown in Fig. 2. The films were placed sequentially with different concentrations of SiO_2/NiO nanoparticles. Image (*a*) in Fig. 2 for the polymer mix appears to be clear, linked, and to have a constant form, revealing a somewhat smooth surface [29, 30]. As the ratio of SiO_2/NiO nanoparticles increases, the surface morphology of the polymer mixtures PVA/PEG in Fig. 2, *b*, *c*, *d*, and *e* varies. Furthermore, the surface of nanocomposites films exhibits a large number of equally distributed, widely varying elliptical particle ag-

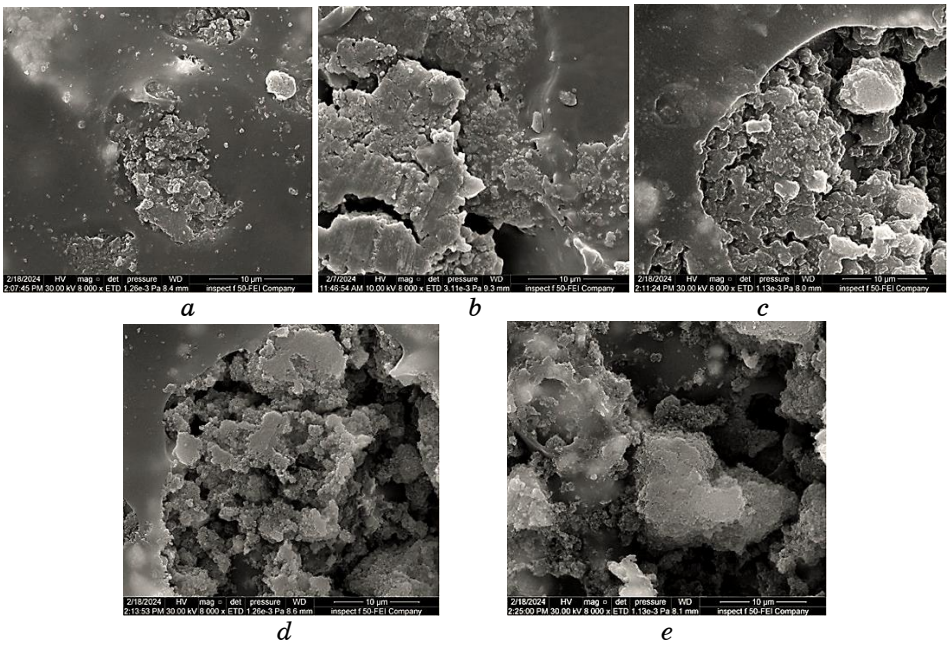

Fig. 2. SEM images of PVA–PEG–SiO_2–NiO NCs: *a*—PVA–PEG; *b*—2 wt.% SiO_2–NiO; *c*—4 wt.% SiO_2–NiO; *d*—6 wt.% SiO_2–NiO; *e*—8 wt.% SiO_2–NiO.

gregates or pieces, which could indicate a uniform growth process [31, 32]. As the nanoparticle ratio in polymer blends increases, surface form evolves. When the concentrations of SiO_2/NiO NCs increase, the grains agglomerate and converge, and more aggregates or fragments are randomly distributed on the upper surface of the nanoparticles [33–36], as shown in Fig. 2, *e*.

3.3. Application of PVA–PEG–SiO_2–NiO NCs for Gamma-Ray Shielding

The percentages of silicon dioxide/nickel oxide SiO_2–NiO nanoparticles are positively correlated with the natural logarithm of the ratio of N to N_0 for polymer mixtures PVA/PEG, as demonstrated in Fig. 3. Table presents the values, which were achieved. The fluctuation of gamma-radiation attenuation coefficients for PVA/PEG polymer mixes as a function of SiO_2–NiO-nanoparticles' ratios is displayed in Fig. 4. The PVA/PEG-polymer blends exhibited promising radiation absorption capabilities. As SiO_2–NiO-nanoparticles' concentration increases; so, the attenuation coefficients do. This is so because the substance used to make shielding materials is PNC, by

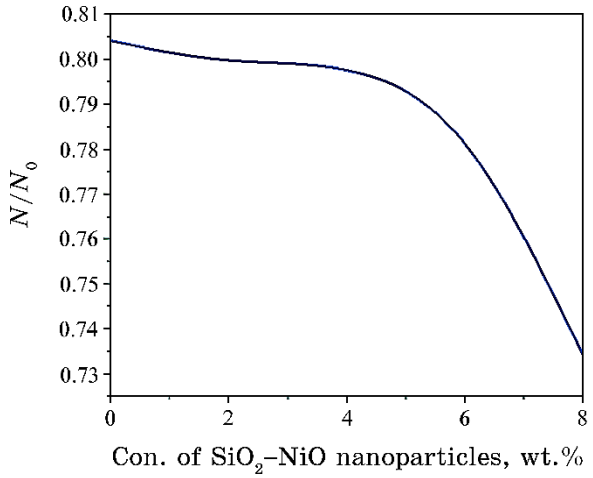

Fig. 3. Variability of N/N_0 for PVA/PEG-polymer blends with varying SiO_2–NiO-NPs' ratios.

TABLE. Values of N/N_0, $\ln(N/N_0)$, and μ [cm^{-1}] for PVA–PEG–SiO_2–NiO PNC.

Content of SiO_2–NiO nanoparticles, wt.%	N/N_0	$\ln(N/N_0)$	μ, cm^{-1}
0	0.804	0.2180	0.002704
2	0.799	0.2234	0.001357
4	0.797	0.2261	0.010378
6	0.781	0.2469	0.031016
8	0.734	0.3089	0.038618

which gamma rays can be reflected, scattered, or absorbed [37, 38].

The gamma-radiation attenuation coefficient numbers for PNC are as high as 0.03861 cm^{-1}. When compared, the results of polymer PNC and concrete indicated a great deal of similarities, as seen in the figure below. Because of the polymer nanocomposite increased mobility, lack of electrical conductivity, and ability to prevent neutron escape, it demonstrated better characteristics than concrete [39–41]. Furthermore, growing $\ln(N/N_0)$ of the PVA/PEG mixture is observed in Fig. 5 along with rising SiO_2–NiO-NPs' concentrations [42, 43]. Table shows N/N_0, $\ln(N/N_0)$, and μ [cm^{-1}] values for PVA–PEG–SiO_2–NiO PNC.

4. CONCLUSIONS

In the present investigation, the casting solution method of production was used for manufacturing plastic nanocomposite films.

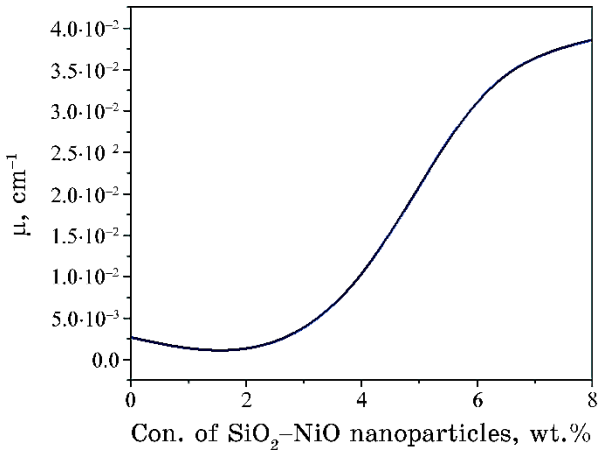

Fig. 4. Variability of μ [cm^{-1}] for PVA/PEG-polymer blends with varying SiO_2–NiO-NPs' ratios.

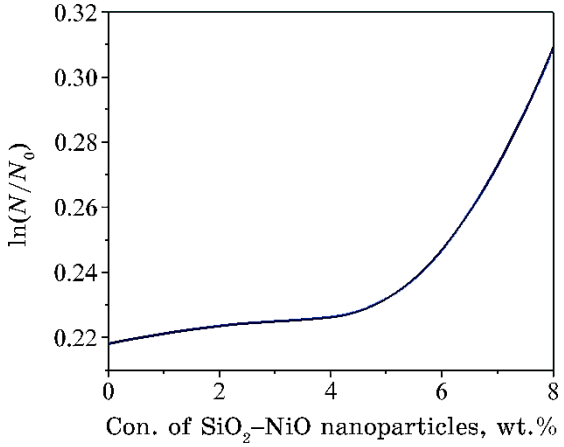

Fig. 5. Variability of $\ln(N/N_0)$ for PVA/PEG-polymer blends with varying SiO_2–NiO-NPs' ratios.

The film consists of a mixture of PVA/PEG as the basic matrix and SiO_2–NiO nanoparticles added in variable proportions. The optical-microscope photographs illustrate that the SiO_2–NiO additions were dispersed uniformly, and the nanoparticles organized into a consecutive network inside the polymer mixture. SEM examination was performed on the top surface of the PVA–PEG–SiO_2–NiO-NCs' films to examine the surface morphology. The findings point to the existence of several aggregates or pieces, which were dispersed randomly over the surface. Eventually, when the amount of SiO_2–NiO

nanoparticles increases, the attenuation coefficient for gamma radiation climbs as well. The results of the investigation display that the PVA–PEG–SiO_2–NiO-nanocomposite films exhibit good gamma-ray shielding features, when employed as a lead-free material. This implies that it may be a good substitute for traditional shielding materials in the field of nuclear medicine.

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