

PACS numbers: 68.37.Hk, 68.55.J-, 81.07.Pr, 81.70.Fy, 82.35.Np

Synthesis, Characterization and Application of PVA– CMC/SiO₂–Cr₂O₃ Nanostructures

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This study investigates the synthesis of new nanocomposites (NCs) comprising polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) with silicon dioxide (SiO₂) and chromium trioxide (Cr₂O₃) for the use in gamma-rays'-shielding applications. The nanocomposites exhibit desirable properties such as low weight, elasticity, high attenuation coefficients, and cost-effectiveness for gamma-rays' shielding. The structural properties of PVA–CMC–SiO₂–Cr₂O₃ nanocomposites are studied. The scanning electron microscopy reveals that the top surface of the PVA–CMC/SiO₂–Cr₂O₃ NCs films exhibits uniform and cohesive aggregates or fragments distributed randomly, when the weight percentage reaches 8%. The uniform distribution of nanoparticles (NPs) in the blend is evidenced by the optical microscope images and leads to a continuous network within the polymer matrix. The study results regarding the utilization of gamma-rays' shielding demonstrate that the nanocomposites composed of PVA–CMC/SiO₂–Cr₂O₃ display significant attenuation coefficients for gamma rays.

У цьому дослідженні досліджується синтез нових нанокompозитів (НК), що складаються з полівінілового спирту (ПВА) та карбоксиметилцелюлози (КМЦ) з діоксидом Силіцію (SiO₂) та триоксидом Хрому (Cr₂O₃) для використання в екрануванні гамма-променів. Нанокompозити демонструють такі бажані властивості, як мала вага, пружність, високі коефіцієнти загасання й економічність для екранування гамма-променів. Досліджено структурні властивості нанокompозитів ПВА–КМЦ–SiO₂–Cr₂O₃. Сканувальна електронна мікроскопія показує, що верхня поверхня плівок ПВА–КМЦ/SiO₂–Cr₂O₃ НК демонструє однорідні та зв'язані агрегати або фрагменти, розподілені випадковим чином, коли ваговий відсоток досягає 8%. Рівномірний розподіл наночастинок (НЧ) у суміші підтверджується зображеннями в оптичному мікроскопі та приводить до безперервної мережі всередині полімерної матриці. Результати дослідження щодо використання екранування гамма-променів

демонструють, що наноккомпозити, які складаються з ПВА–КМЦ/SiO₂–Cr₂O₃, демонструють значні коефіцієнти загасання гамма-променів.

Key words: nanocomposites, SiO₂–Cr₂O₃ nanoparticles, polyvinyl alcohol, carboxymethyl cellulose, structural properties, gamma-rays' shielding.

Ключові слова: наноккомпозити, наночастинки SiO₂–Cr₂O₃, полівініловий спирт, карбоксиметилцелюлоза, структурні властивості, екранування гамма-променів.

(Received 30 June, 2023)

1. INTRODUCTION

Nanotechnology is a nascent scientific discipline that emerged from the observation that materials exhibit markedly distinct characteristics at the nanoscale in contrast to their properties at larger particle sizes [1]. Nanotechnologies are considered crucial technologies of the current century, and significant research endeavours are being undertaken in this domain. There is a possibility that additional applications will be accessible shortly. Nanotechnology exhibits significant potential across multiple domains due to the distinctive physical, chemical, and biological properties of structural features at the nanoscale compared to their macroscopic counterparts [2, 3]. The field of nanomaterials research adopts a materials science-oriented methodology in the realm of nanotechnology. One nanometer (nm) is one billionth of a meter. Nanomaterials are materials with a characteristic unit size ranging from 1 to 100 nanometers. The distinctive characteristics of these materials are frequently attributed to their dimensions, morphology, and chemical constitution [4]. Two primary factors contribute to nanomaterials' distinct properties compared to other materials. The augmentation of the relative surface area and the manifestation of quantum effects are being considered [5]. Nanocomposites are composite materials containing at least one nanometric scale component (10^{-9} m) [6].

Nanocomposites (NCs) are composed of polymers, both natural and synthetic and nanomaterials. The term 'nanomaterials' refers to materials, which possess topography at the nanoscale or are constructed of nanosize building components. Nanocomposites' fundamental concept involves establishing a substantial interface between the polymer matrix and the nanosize constituent units. Nanocomposites' mechanical, electrical, thermal, optical, electrochemical, and catalytic properties are expected to exhibit significant differences from those of their constituent materials [7, 8]. Polyvinyl alcohol (PVA) is a water-soluble synthetic polymer. Its low toxicity and exceptional properties characterize it as a wound dressing and biore-

actor material. PVA is characterized by its semi-crystalline nature, attributed to the coexistence of amorphous and crystalline regions. This unique feature results in interfacial effects that enhance the materials' physical properties [9, 10].

Polyvinyl alcohol exhibits distinctive characteristics, including biodegradability, environmental sustainability, good chemical stability, elongation, tensile strength, elevated abrasion resistance, good charge storage capacity, flexibility, facile film process ability, thermal stability, and economical manufacturing expenses [11, 12]. The substance undergoes rapid decomposition when exposed to elevated temperatures. Various additives, including polymers, salts, nanocomposites, and ions, are commonly incorporated into polyvinyl alcohol (PVA) to enhance and alter its characteristics [13]. PVA exhibits inadequate electrical insulation properties, but can acquire conductivity upon doping with certain inorganic fillers [14].

Carboxymethyl cellulose (CMC) is a significant polymer in various industrial sectors such as drag reduction, detergents, drugs, paper, and oil well drilling operations, textiles, and foods. The diverse characteristics of carboxymethyl cellulose are contingent upon three key factors: the distribution of carboxyl substituents along the polymer chains, the average carboxyl content per hydro glucose unit, and the molecular weight of the polymer [15]. The anionic polymer CMC is derived from natural cellulose through chemical modification and is characterized by its biodegradability, biocompatibility, and natural origin [16]. The particles of silicon dioxide (SiO₂) exhibit solid plasticizing properties that have the potential to improve both chemical and mechanical characteristics [17].

Silicon dioxide (SiO₂) is an amorphous, nontoxic material with many potential applications. Nanofillers composed of fumed silicon dioxide (SiO₂) are utilized in electronics and thermoplastic polymers [18]. SiO₂ nanoparticles are utilized as additives in electronic packaging and thermoplastic polymers [19]. Chromium oxide (Cr₂O₃) is classified as a *p*-type metal oxide semiconductor with a hexagonal crystal structure. It possesses remarkable properties, including exceptional decay resistance, the ability to conduct electricity, and a high melting point. These valuable properties have enabled its application in various practical biomedical contexts. The utilization of Cr₂O₃ nanoparticles as a highly effective catalyst in chemical reactions has been observed [20]. The radiation phenomenon is characterized by the transfer of energy from a source through space, which can penetrate various materials [21]. Synthetic polymers have the potential to be utilized in the production of innovative materials that can serve as radiation shielding. Moreover, the supplementary benefits of low industrial cost, durability, and high chemical and thermal stability are among the favoured characteristics and quali-

ties of enhanced shielding [22]. The present study endeavours to fabricate a nanosystem comprising PVA, CMC, SiO₂, and Cr₂O₃ for radiation attenuation.

2. EXPERIMENTAL PART

Silicon dioxide (SiO₂)-chromium trioxide (Cr₂O₃) nanoparticles (NPs) were used in various weight percentages in the films of nanocomposites (0, 2, 4, 6, and 8 wt.%), which were created using the casting process.

The process involved dissolving pure PVA and CMC (68/32) in 40 ml of distilled water for 40 minutes while stirring with a magnetic stirrer at 70°C to achieve a more homogeneous solution; this resulted in the creation of PVA-CMC-SiO₂-Cr₂O₃ nanocomposite films. The fluid was confined within a Petri dish. The resultant solution was subjected to a four-day drying period at ambient temperature after synthesizing polymer mixture nanocomposites.

To measure, NCs were removed from the petri dish and used. The surface morphology of the PVA-CMC-SiO₂-Cr₂O₃ nanocomposites was observed using a scanning electron microscope (Model/Mira-3; Details/1.2 nm at 30 kV; 2.3 nm at 3 kV; Manufacturing and Country/Tescan, France) and an Olympus type Nikon-73346 optical microscope with a magnifying power of ×10 and a camera for microscopic photography was utilized.

The present study investigates the gamma ray attenuation properties of SiO₂-Cr₂O₃ nanoparticles with varying volume fractions, utilizing nanocomposites for gamma ray shielding. Samples were positioned before a collimated beam from gamma-ray sources (Cs-137.5 mci). The separation between the gamma ray and the detector is 2 cm. The present study involved the determination of linear attenuation coefficients through the utilization of Geiger counter measurements. The measurements were conducted on transmitted gamma ray fluxes that passed through nanocomposites composed of PVA-CMC-SiO₂-Cr₂O₃ NCs.

The equation presented below can be utilized to calculate the linear attenuation coefficients (μ) based on the material thicknesses [23]:

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

where the number of radiation particles, denoted as N_0 , detected over a specified time interval in the absence of an absorber, and the attenuation coefficient of gamma radiation, represented by μ . Additionally, the study examines the number of particles, denoted as N , detected over the same time interval when a sample of thickness x is introduced.

3. RESULTS AND DISCUSSIONS

3.1. Scanning Electron Microscope (SEM) Measurements of PVA-CMC/SiO₂-Cr₂O₃ NCs

Scanning electron microscopy (SEM) images give a good impression of the size and morphology of PVA-CMC/SiO₂-Cr₂O₃ nanocomposites in Fig. 1. The findings indicate that the polymer image (a) exhibits soft-

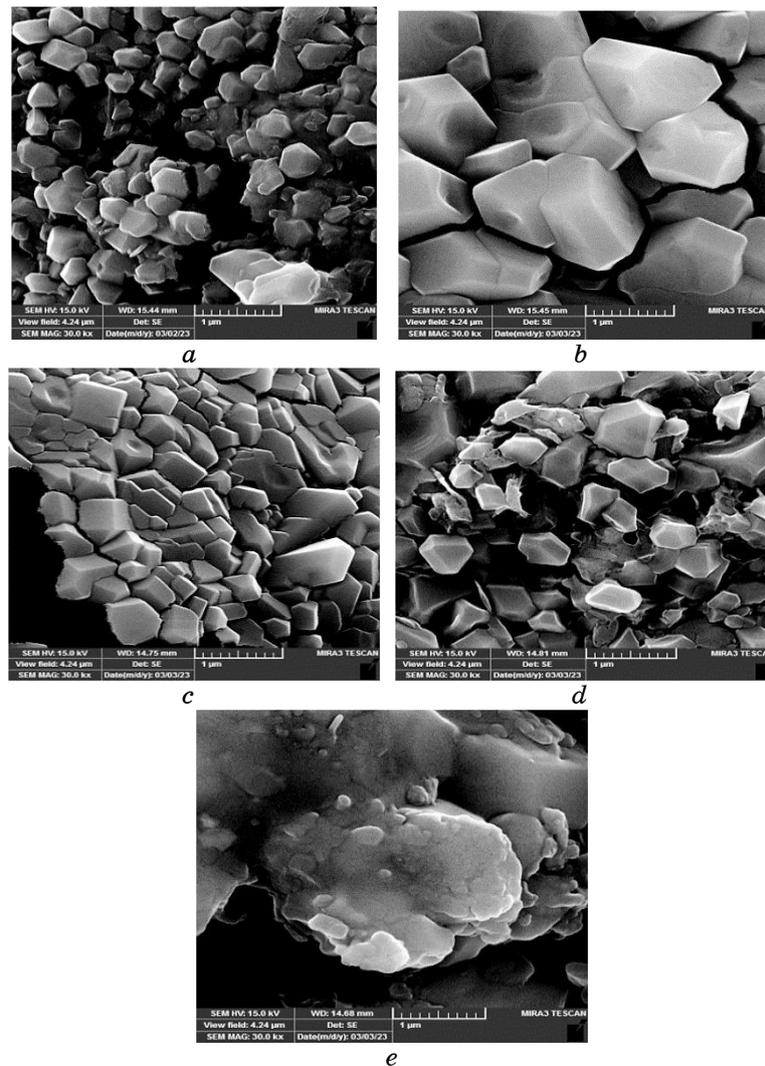


Fig. 1. SEM images of PVA-CMC/SiO₂-Cr₂O₃ NCs: (a) PVA-CMC; (b) 2 wt.% SiO₂-Cr₂O₃; (c) 4 wt.% SiO₂-Cr₂O₃; (d) 6 wt.% SiO₂-Cr₂O₃; (e) 8 wt.% SiO₂-Cr₂O₃.

ness, uniformity, and coherence [21]. The alterations in the surface morphology of PVA–CMC/SiO₂–Cr₂O₃ nanocomposites are observed to be correlated with the incorporation of SiO₂ and Cr₂O₃ nanoparticles, as depicted in Figs. 1, *b*, *c*, *d* and *e*. The photographic evidence indicates that the size of granule particles is increasing with the augmentation of the SiO₂ and Cr₂O₃ nanoparticles' content.

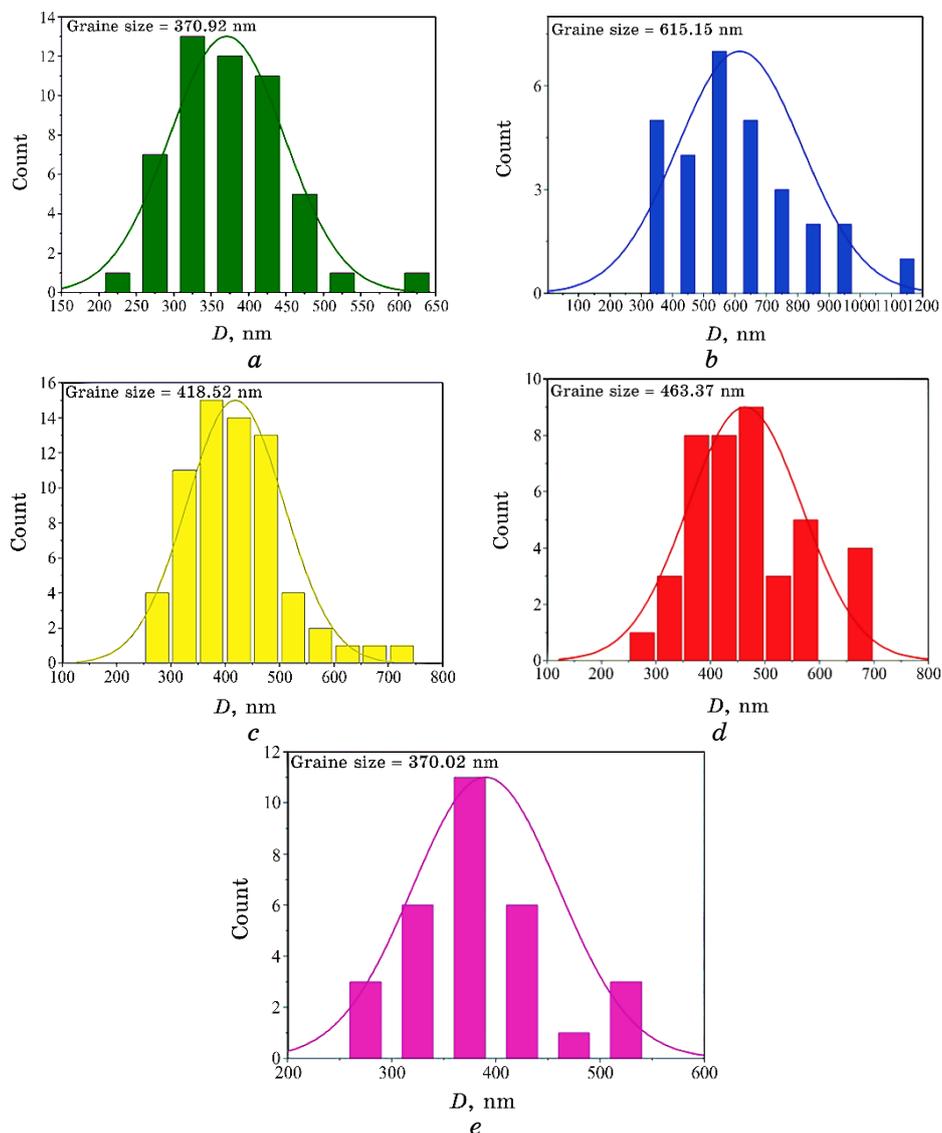


Fig. 2. Grain size for PVA–CMC/SiO₂–Cr₂O₃ NCs: (a) PVA–CMC; (b) 2 wt.% SiO₂–Cr₂O₃; (c) 4 wt.% SiO₂–Cr₂O₃; (d) 6 wt.% SiO₂–Cr₂O₃; (e) 8 wt.% SiO₂–Cr₂O₃.

The surface morphology of the nanocomposites composed of PVA, CMC, SiO₂, and Cr₂O₃ displays numerous dispersed lumps or pieces on the top surface. The image depicts how the amount of silicon dioxide (SiO₂) and chromium trioxide (Cr₂O₃) nanoparticles on the surface increases as their concentration rises [24–27]. Figure 2 shows the grain size for PVA-CMC/SiO₂-Cr₂O₃ nanocomposites calculate from SEM images.

3.2. Optical Microscope for PVA-CMC-SiO₂-Cr₂O₃ NCs

Figure 3 displays magnified images of PVA-CMC-SiO₂-Cr₂O₃)

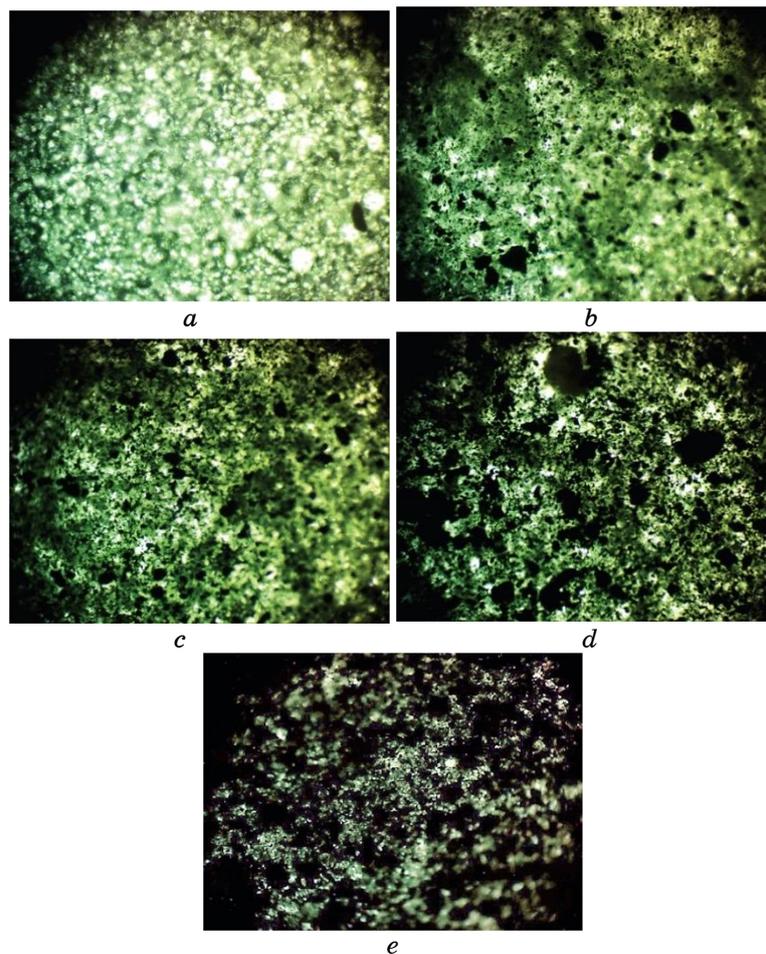


Fig. 3. Optical microscope images of PVA-CMC/SiO₂-Cr₂O₃ NCs at a magnification ($\times 10$): (a) PVA-CMC; (b) 2 wt.% SiO₂-Cr₂O₃; (c) 4 wt.% SiO₂-Cr₂O₃; (d) 6 wt.% SiO₂-Cr₂O₃; (e) 8 wt.% SiO₂-Cr₂O₃.

nanocomposite films at different concentrations. The nanocomposites exhibited distinguishable characteristics between the $\text{SiO}_2\text{-Cr}_2\text{O}_3$ nanoparticles and the PVA/CMC blend. Upon incorporating $\text{SiO}_2\text{-Cr}_2\text{O}_3$ nanoparticles into the polymeric blend, they exhibit a uniform dispersion throughout the blend and a high degree of proximity. Upon reaching a concentration of 8 wt.%, the $\text{SiO}_2\text{-Cr}_2\text{O}_3$ particles transition to form a cohesive network. Nanoparticles are linked within polymers, specifically in polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC), in the context of films. The network depicted in Figs. 3, *a*, *b*, *c*, *d*, and *e* facilitates the movement of charge carriers, resulting in a modification of the material characteristics [28–30].

3.3. Application of PVA–CMC/ $\text{SiO}_2\text{-Cr}_2\text{O}_3$ NCs for Gamma-Rays' Shielding

Figure 4 illustrates the oscillations of (N/N_0) in PVA–CMC composites with different concentrations of $\text{SiO}_2\text{-Cr}_2\text{O}_3$ nanoparticles. The attenuation of radiation increases due to the rise in concentrations of $\text{SiO}_2\text{-Cr}_2\text{O}_3$ nanoparticles, leading to a decrease in transmission radiation [31–33]. Figure 5 shows increasing $\ln(N/N_0)$ of PVA/CMC mixture with increases of $\text{SiO}_2\text{-Cr}_2\text{O}_3$ NPs concentrations [34].

The graphical representation in Fig. 6 depicts the fluctuation in attenuation coefficients of gamma radiation concerning the concentrations of $\text{SiO}_2\text{-Cr}_2\text{O}_3$ nanoparticles in a PVA–CMC blend. The escalation observed in attenuation coefficients with increasing nanopar-

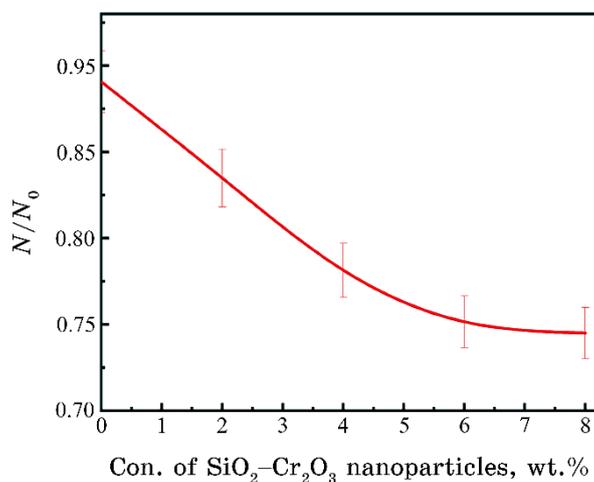


Fig. 4. Variance of (N/N_0) for PVA/CMC mixture with different concentrations of $\text{SiO}_2/\text{Cr}_2\text{O}_3$ NPs.

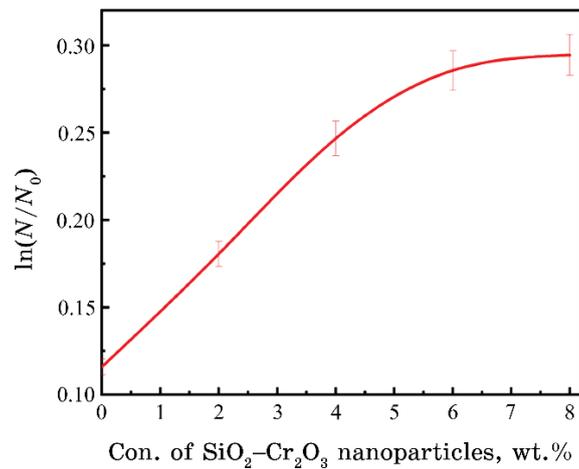


Fig. 5. Change of $\ln(N/N_0)$ for PVA/CMC blend with different concentrations of SiO₂/Cr₂O₃ nanoparticles

title concentrations can be attributed to the absorption or reflection of gamma radiation by the nanocomposite shielding materials, as documented in Refs. [35–39].

Upon comparison, the outcomes of polymer nanocomposites and concrete, as depicted in figure below, exhibited a high degree of similarity. The composite polymer exhibited superior properties to concrete owing to its enhanced mobility, absence of electrical con-

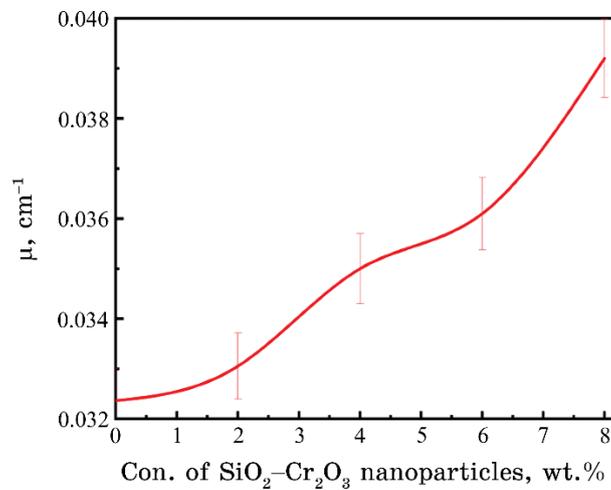


Fig. 6. Variance of attenuation coefficients of gamma radiation for PVA/CMC blends with different concentrations of SiO₂/Cr₂O₃ nanoparticles.

ductivity, and potential to impede the escape of neutrons [40–43].

4. CONCLUSIONS

The present study involved the production of plastic nanocomposite films utilizing the casting solution fabrication method. The films were comprised of silicon dioxide (SiO_2), chromium trioxide (Cr_2O_3) nanoparticles, polyvinyl alcohol (PVA), and carboxymethyl cellulose (CMC). The top surface of the PVA–CMC/ SiO_2 – Cr_2O_3 NCs films was analysed using SEM to depict its surface morphology. The results revealed the presence of diverse fragments or aggregates that were randomly dispersed across the surface. When silicon dioxide (SiO_2) and chromium trioxide (Cr_2O_3) nanoparticles are formed in a polymer mixture at a concentration of eight percent by weight, images taken using an optical microscope (OM) reveal that they form a continuous network. Finally, as concentration NPs increases, the attenuation coefficient rises for gamma radiation with an increase in the concentration of SiO_2 – Cr_2O_3 nanoparticles.

REFERENCES

1. A. J. Hassan, *Journal of Modern Physics*, **5**, No. 18: 2184 (2014); <https://doi.org/10.4236/jmp.2014.518212>
2. M. A. Habeeb, *European Journal of Scientific Research*, **57**, No. 3: 478 (2011).
3. A. Khan, *Journal of Nanomaterials*, **2012**: 66 (2012).
4. M. A. Habeeb and Z. S. Jaber, *East European Journal of Physics*, **4**: 176 (2022); [doi:10.26565/2312-4334-2022-4-18](https://doi.org/10.26565/2312-4334-2022-4-18)
5. A. H. Hadi and M. A. Habeeb, *Journal of Mechanical Engineering Research and Developments*, **44**, No. 3: 265 (2021); <https://jmerd.net/03-2021-265-274>
6. Q.M. Jebur, A. Hashim, and M. A. Habeeb, *Egyptian Journal of Chemistry*, **63**: 719 (2020); <https://dx.doi.org/10.21608/ejchem.2019.14847.1900>
7. N. Othman, N. A. Azahari, and H. Ismail, *Malaysian Polymer Journal*, **6**, No. 6: 147 (2011).
8. S. M. Mahdi and M. A. Habeeb, *Optical and Quantum Electronics*, **54**, Iss. 12: 854 (2022); <https://doi.org/10.1007/s11082-022-04267-6>
9. N. Hayder, M. A. Habeeb, and A. Hashim, *Egyptian Journal of Chemistry*, **63**: 577 (2020); [doi:10.21608/ejchem.2019.14646.1887](https://doi.org/10.21608/ejchem.2019.14646.1887)
10. J. Selvi, S. Mahalakshmi, and V. Parthasarathy, *Journal of Inorganic and Organometallic Polymers and Materials*, **27**: 1918 (2017); <https://doi.org/10.1007/s10904-017-0662-1>
11. M. A. Habeeb, A. Hashim, and N. Hayder, *Egyptian Journal of Chemistry*, **63**: 709 (2020); <https://dx.doi.org/10.21608/ejchem.2019.13333.1832>
12. A. Hashim, M. A. Habeeb, and Q. M. Jebur, *Egyptian Journal of Chemistry*, **63**: 735 (2020); <https://dx.doi.org/10.21608/ejchem.2019.14849.1901>

13. S. M. Mahdi and M. A. Habeeb, *Physics and Chemistry of Solid State*, **23**, No. 4: 785 (2022); doi:10.15330/pcss.23.4.785-792
14. F. Liu, S. Wang, M. Zhang, M. Ma, C. Wang, and J. Li, *Applied Surface Science*, **280**: 686 (2013); <https://doi.org/10.1016/j.apsusc.2013.05.043>
15. M. A. Habeeb and W. S. Mahdi, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 9: 247 (2019); doi:10.30534/ijeter/2019/06792019
16. M. A. Habeeb and R. S. Abdul Hamza, *Journal of Bionanoscience*, **12**, No. 3: 328 (2018); <https://doi.org/10.1166/jbns.2018.1535>
17. M. Barakat, R. Bahareth, E. Mahrous, S. Aldawood, and S. Nouh, *The European Physical Journal Applied Physics*, **97**: 35 (2022); <https://doi.org/10.1051/epjap/2022210268>
18. M. A. Habeeb, A. Hashim, and N. Hayder, *Egyptian Journal of Chemistry*, **63**: 697 (2020); <https://dx.doi.org/10.21608/ejchem.2019.12439.1774>
19. M. A. Habeeb and W. K. Kadhim, *Journal of Engineering and Applied Sciences*, **9**, No. 4: 109 (2014); doi:10.36478/jeasci.2014.109.113
20. K. Rajesh, V. Crasta, K. N. B. Rithin, G. Shetty, and P. D. Rekha, *J. Polym. Res.*, **26**, No. 4: 1 (2019); <https://doi.org/10.1007/s10965-019-1762-0>
21. M. A. Habeeb, *Journal of Engineering and Applied Sciences*, **9**, No. 4: 102 (2014); doi:10.36478/jeasci.2014.102.108
22. J. B. Ramesh and K. K. Vijaya, *Chemtech.*, **7**: 171 (2014).
23. S. M. Mahdi and M. A. Habeeb, *Digest Journal of Nanomaterials and Biostructures*, **17**, No. 3: 941 (2022); <https://doi.org/10.15251/DJNB.2022.173.941>
24. S. Ju, M. Chen, H. Zhang, and Z. Zhang, *Journal of express Polymer Letters*, **8**, No. 9: 682 (2014); <https://doi.org/10.3144/expresspolymlett.2014.71>
25. A. H. Hadi and M. A. Habeeb, *Journal of Physics: Conference Series*, **1973**, No. 1: 012063 (2021); doi:10.1088/1742-6596/1973/1/012063
26. Q. M. Jebur, A. Hashim, and M. A. Habeeb, *Egyptian Journal of Chemistry*, **63**, No. 2: 611 (2020); <https://dx.doi.org/10.21608/ejchem.2019.10197.1669>
27. G. Aras, E. L. Orhan, I. F. Selçuk, S. B. Ocak, and M. Ertuğrul, *Procedia-Social and Behavioral Sciences*, **95**: 1740 (2015); <https://doi.org/10.1016/j.sbspro.2015.06.295>
28. M. Roy, J. AK Bajpai, and R. G Mahloniya, *Advanced Materials Letters*, **3**, No. 5: 426 (2012); <https://doi.org/10.5185/amlett.2012.6373>
29. M. H. Dwech, M. A. Habeeb, and A. H. Mohammed, *Ukr. J. Phys.*, **67**, No. 10: 757 (2022); <https://doi.org/10.15407/ujpe67.10.757>
30. S. M. Mahdi and M. A. Habeeb, *Polymer Bulletin*, 2023; <https://doi.org/10.1007/s00289-023-04676-x>
31. M. Martin, N. Prasad, M. M Siva lingam, D. Sastikumar, and B. Karthikeyan, *Journal of Material Science: Material in Electronics*, **29**: 365 (2018); <https://doi.org/10.1007/s10854-017-7925-z>
32. M. A. Habeeb and W. H. Rahdi, *Optical and Quantum Electronics*, **55**, Iss. 4: 334 (2023); <https://doi.org/10.1007/s11082-023-04639-6>
33. A. A. Mohammed and M. A. Habeeb, *Silicon*, **15**: 5163 (2023), <https://doi.org/10.1007/s12633-023-02426-2>

34. R. Dalven and R. Gill, *J. Appl. Phys.*, **38**, No. 2: 753 (1967); [doi:10.1063/1.1709406](https://doi.org/10.1063/1.1709406)
35. N. K. Al-Sharifi and M. A. Habeeb, *Silicon*, **15**: 4979 (2023); <https://doi.org/10.1007/s12633-023-02418-2>
36. R. N. Bhagat and V. S. Sangawar, *Int. J. Sci. Res. (IJSR)*, **6**: 361 (2017).
37. R. S. Abdul Hamza and M. A. Habeeb, *Optical and Quantum Electronics*, **55**, Iss. 8: 705 (2023); <https://doi.org/10.1007/s11082-023-04995-3>
38. A. Goswami, A. K. Bajpai, and B. K. Sinha, *Polym. Bull.*, **75**, No. 2: 781 (2018); <https://doi.org/10.1007/s00289-017-2067-2>
39. S. M. Mahdi and M. A. Habeeb, *AIMS Materials Science*, **10**, No. 2: 288 (2023); [doi:10.3934/mat.2023015](https://doi.org/10.3934/mat.2023015)
40. O. E. Gouda, S. F. Mahmoud, A. A. El-Gendy, and A. S. Haiba, *Indonesian Journal of Electrical Engineering*, **12**, No. 12: 7987 (2014); <https://doi.org/10.11591/telkomnika.v12i12.6675>
41. M. A. Habeeb and R. S. A. Hamza, *Indonesian Journal of Electrical Engineering and Informatics*, **6**, No. 4: 428 (2018); [doi:10.11591/ijeel.v6i1.511](https://doi.org/10.11591/ijeel.v6i1.511)
42. A. R. Farhadizadeh and H. Ghomi, *Materials Research Express*, **7**, No. 3: 36502 (2020); <https://doi.org/10.1088/2053-1591/ab79d2>
43. P. Vasudevan, S. Thomas, K. Arunkumar, S. Karthika, and N. Unnikrishnan, *Journal of Materials Science and Engineering*, **73**: 1 (2015); [doi:10.1088/1757-899X/73/1/012015](https://doi.org/10.1088/1757-899X/73/1/012015)