



Synthesis of (PVA/PEG: ZnO and Co₃O₄) Nanocomposites: Characterization and Gamma Ray Studies

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Abstract

Polymer blend (PVA/PEG) and its nanocomposites with constant ZnO and different ratios of Co₃O₄ NPs films synthesized using solution cast technique. The obtained products were identified by Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD), and scanning electron microscopy (SEM). Optical characteristics have been studied by UV-visible spectroscopy. FT-IR spectra confirmed the presence of the functional groups present in polymer nanocomposite systems. XRD analysis confirmed the formation of nanocomposite films more crystalline from the polymeric matrix. SEM showed a powerful dispersion of ZnO and Co₃O₄ NPs on the surface of the polymeric matrix. The D.C electrical conductivity of the polymeric system (PVA/PEG) increases after addition of ZnO and Co₃O₄ NPs for all temperatures under test. D.C measurements indicate that all films having one activation energy, and that its value increases with the increase in the percentage of addition. The A.C electrical properties showed that the dielectric constant and dielectric loss for all films decreases with the increase of the electric field frequency, and that its values increase with the increasing of the wt.% of Co₃O₄ NPs. The (PVA/PEG) and its nanocomposite with ZnO and different wt.% of Co₃O₄ films have good linear attenuation coefficients for gamma ray radiation.

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Key Words: (PVA/PEG) Films, ZnO and Co₃O₄ NPs, Electrical Properties, Gamma Ray.

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Introduction

The synthesis and investigation of various polymer blends has sparked a lot of interest in recent years. The service properties of polymeric materials can be enhanced by mixing two or more polymers or suitable dopant (Nandi et al., 2014). Furthermore, several researchers are interested in developing polymeric materials' electrical and magnetic properties (P. Liu et al., 2019). Using inorganic nanomaterials to dope polymers also opens up a new realm of experimental and technological possibilities. PVA (polyvinyl alcohol) is a nontoxic, biocompatible substance, and noncarcinogenic semi-crystalline polymer. Its hydrophilicity makes

it suitable for use in the creation of composite films (Sheha et al., 2013). When exposed to UV-visible light, PVA has excellent dimensional stability and is photo-stable. It also has a low oxygen permeability. This is because the highly polar alcohol produces a lot of inter-cohesive energy (-OH) group (Mahendia et al., 2011). Polyethylene glycol (PEG) is one of most common preferred polymers for the increasing and production of numerous important applications (Abdelamir et al., 2020). PEG is known for its high mobility and is water soluble. It is used as a binder in the formation of ceramic products because of its well-known properties such as lack of toxicity and toughness.

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The strong hydrogen bonding capacity of PVA is expected to interact with PEG, resulting in a new polymer known as (PVA/PEG) with better properties like PVA porosity control and super-molecular structure (P. Liu et al., 2019). The ability of PEG to dissolve in water gave them a variety of properties, including resistance to solvents and oils, as well as the ability to act as excellent cellulosic adhesion materials. It has a wide range of uses significant industrial applications, including paper, textiles, and the coating of photographic films with oxygen-resistant membranes, thanks to its special properties. Metal oxides are used in a number of fields, including technology, environmental remediation, photocatalysis, solar energy transfer, and electronics (Mohamed & Abdel-Kader, 2019). Zinc oxide (ZnO) has sparked widespread interest due to its excellent photocatalytic activity, high stability, antibacterial properties, and lack of toxicity. The piezoelectric biosensors, food additives, and catalysis are only a handful of the uses for ZnO nanostructures in biomedical fields (Y. Liu & Kim, 2012). Because of its affordable prices, controllable dimension, shape, tunable surface, and structural features, in many applications consider Co₃O₄ to be a promising candidate. This substance has no impact on environment, has a spinel structure, mixed valence (Co_{II} and Co_{III}) (Bilkan et al., 2017). The new research deals with the synthesis innovative nanocomposites (PVA/PEG: ZnO and Co₃O₄) with the aim of evaluating their structural and electrical properties for gamma ray shielding.

Material and Method

Materials

The polymers PVA (partially hydrolysis, Mol. wt. = 160,000 g/mol) and PEG (degree of hydrolysis=99%, Mol. wt. = 20,000 g/mol) are applied as granular form, water-soluble synthetic polymer, and could be obtained from (Central Drug House, Ltd, Company), Indi. The additive nanomaterials were zinc oxide ZnO (Mol. wt. = 81.408 g/mol). and cobalt oxide Co₃O₄ (Mol. wt. = 240.797 g/mol).

Purification of Polymer Blend and its Nanocomposites

Films of (PVA/PEG) polymer blend and its nanocomposites with ZnO and various ratios of wt.% Co₃O₄ NPs were prepared by solution cast method. 0.9g of PVA was dissolving in (50 ml) of water which is deionized. The solution were prepared by mixing with a magnetic stirrer firstly

for 1hr at RT, then continue for another hour under the temperature of 75-80°C until PVA was completely soluble, then add 0.1g of PEG (after leaving the aqueous solution cooled to 40°C for ½ hr) to obtain a clear solution. The resulting solution was cast onto very clean and dried glasses Petri dishes, and kept at RT under air for 240hr till the solvent is completely evaporated from the films for the drying process. In order to prevent the moisture effect once used, the synthesized dried film is then peeled off from the Petri dishes and kept in vacuum desiccators.

After many experimental trials, acceptable nanocomposite films from PVA / PEG with 5wt% ZnO and different ratios of (1, 2, and 3) wt.% Co₃O₄ (as listed in Table 1), it was obtained according to the following: firstly we used the solid state method for mixing the ZnO and Co₃O₄ NPs alone, which include dissolving it by ethanol solvent with continuous grinding in a crucible ceramic for 90 min. The grinded solution was dried at temperature 60°C for 4 hr before adding it to the polymer solution. Mixture of the polymers were continuing as in previous steps, also achieve a homogeneous solution. The nanocomposites are cast on glass petri dishes using the casting process with an equal volume, then kept at RT under air for 240hr to dry. The thickness of the produced films was between (100-140±4) µm which are measured by Digital Vernier Caliper.

Table 1. The purification tabulated of PVAs, PEGs and nanocomposite films.

Sample	PVA(g)	PEG (g)	ZnO (g)	Co ₃ O ₄ (g)
PVA/PEG	0.9	0.1	0	0
PVA/PEG: ZnO & Co ₃ O ₄	0.846	0.094	0.05	0.01
PVA/PEG: ZnO & Co ₃ O ₄	0.837	0.093	0.05	0.02
PVA/PEG: ZnO & Co ₃ O ₄	0.828	0.092	0.05	0.03

Descriptions

Fourier transform infrared FT-IR spectra (Bruker company, type vertex -70, German origin) were performed to investigate functional groups in polymer blend and its nano-composites with ZnO and Co₃O₄ between 500 cm⁻¹ – 4000 cm⁻¹. The XRD (6000) diffraction system supplied from Japanese company (Shimadzu) was used to describe the crystal structures for the samples under study. The



surface morphology were procured by SEM using INSPECT S50, company, Japan origin, type FEI customer ownership. The UV-Visible spectrophotometer (Shimadzu UV-1650 PC, Phillips, Japanese company) used in the wavelength range (300-1100) nm at RT to record the spectrum of transmission and absorption.

Results and Discussion

Fourier Transform Infrared (FT-IR)

One of the valuable devices to provide useful knowledge about the connections between their functional groups is FT-IR spectroscopy. IR analysis is carried out on a FT-IR transmission profile spectra to characterize the interface of pure (PVA/PEG) polymer blend with 5wt.% ZnO and different ratios of Co₃O₄ (1, 2, and 3 wt.%) NPs under the investigated at RT in wavenumber (500-4000) cm⁻¹ ranges, as shown in Fig. (1). The function groups of PVA-PEG appeared at 3275, 2910, 2360, 1716, 1241, and 1087 cm⁻¹ corresponding to broad band to the hydroxyl groups' stretching vibrations O-H (PVA and PEG), Methyl C-H₃ asymmetric stretching band, medial alkyne (disubstituted) C≡C group, C=O stretching of the ester group carbonyl groups (PVA), O-H ether group bending vibration, C-O stretching vibration (PVA and PEG), respectively. The bands showed at 842, and (660 to 657) cm⁻¹ are allocated to peroxide C-O-O- stretching, and C-H stretching, respectively. contrasting these characteristic wavenumbers with those of (PVA/PEG) blend, it can be It was noticed that the characteristic peaks that indicate the PVA/PEG: ZnO and Co₃O₄ are lightly shifted toward lower or higher wavenumbers, as a result of the addition of ZnO and Co₃O₄ nanoparticles especially at 842 cm⁻¹ and (660 to 657) cm⁻¹ with increasing Co₃O₄ ratio. Thus, the FT-IR spectra confirmed of the produce the functional groups present in polymer nanocomposite systems. The only possible reason for intensity changes and broadening of the functional groups in the backbone of the polymeric matrix is the strong incorporations with Zn⁺² and Co⁺³ ions.

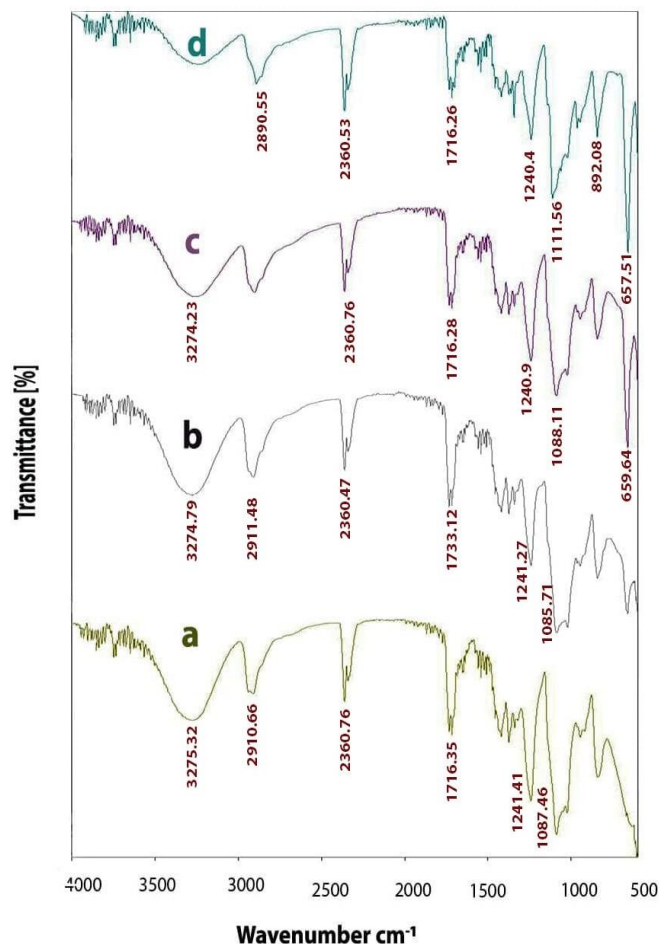


Figure 1. FT-IR spectra of, a. (PVA/PEG) blend, b. (PVA/PEG: ZnO & 1wt.% Co₃O₄), c. (PVA/PEG: ZnO & 2wt.% Co₃O₄), and d. (PVA/PEG: ZnO & 3wt.% Co₃O₄) nanocomposite films

X-Ray Diffraction (XRD) Studies

XRD is a common and non-destructive technique for the study of material crystallographic structures. The XRD spectra of (PVA/PEG) polymer blend and its nanocomposite films with 5wt.% ZnO and different ratios of (1, 2, and 3) wt.% Co₃O₄ NPs are shown in Fig. (2). The lack of sharp peaks of diffraction in the pure polymer blend film indicates dominance of amorphous phase. The 2θ values and planes were respectively 31.55 (100), 34.5 (002), 36.3 ° (101), 47.6 (102), 56.86 (110), 62.9(103), and 68.1 ° (112), which are in close agreement with the values mentioned in the literature (P. Liu et al., 2019) for crystalline hexagonal phase ZnO with lattice constant of a = 3.24982Å and c=5.20661 Å, and are coherent with the reported values (JCPDS Card No. 36-1451). Also, the 2θ values and planes were respectively 31.55 ° (220), 36.8 ° (311), 44.7 ° (400), 55.1 ° (422), 59.1 ° (511), and 65 ° (400), which are in close approval with the values mentioned in the research (Vennela et al., 2019) for crystalline cubic phase Co₃O₄ with lattice

constant of $a = 8.056 \text{ \AA}$, and are coherent with the reported values (JCPDS Card No. 65-3103). The hexagonal ZnO structure peak (101) is dominant in all nanocomposite films. No peaks from other phases of ZnO and Co₃O₄ are noticed; implying the films of high purity from polymer blend and impurities are obtained. The XRD obtained data indicates that when metal oxide was incorporated into (PVA/PEG) polymer blend it became more crystalline than the pure films.

be bended, suggesting greater malleability with mechanical stability and thus greater break elongation (Falqi et al., 2018) (Sengwa & Choudhary, 2014).

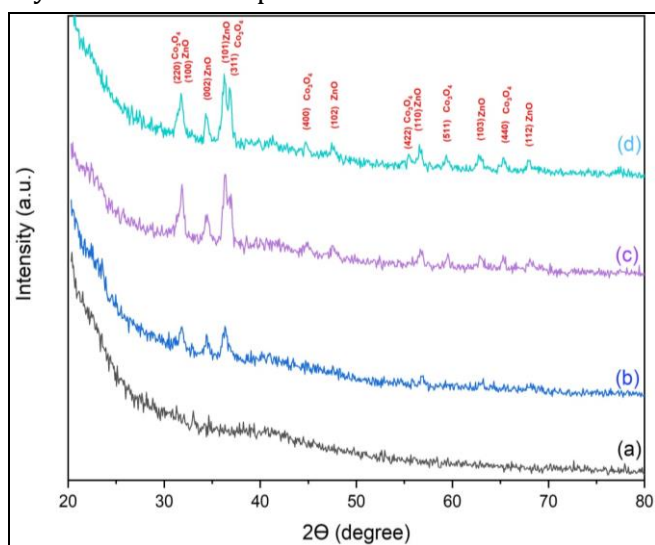
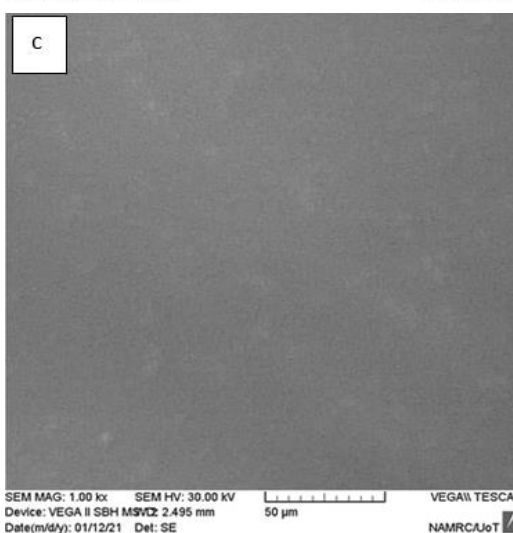
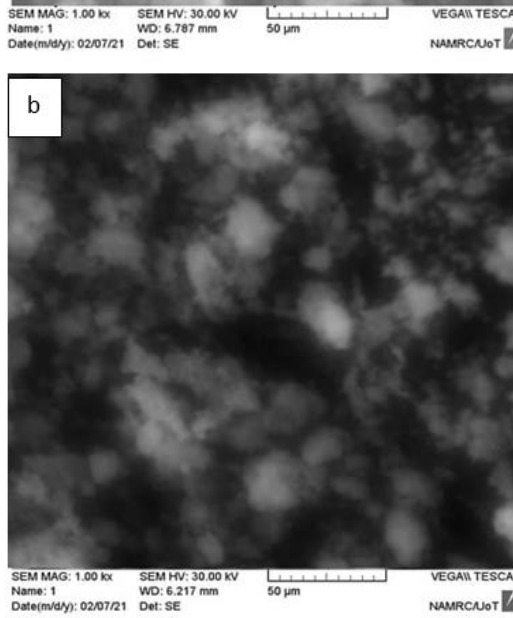
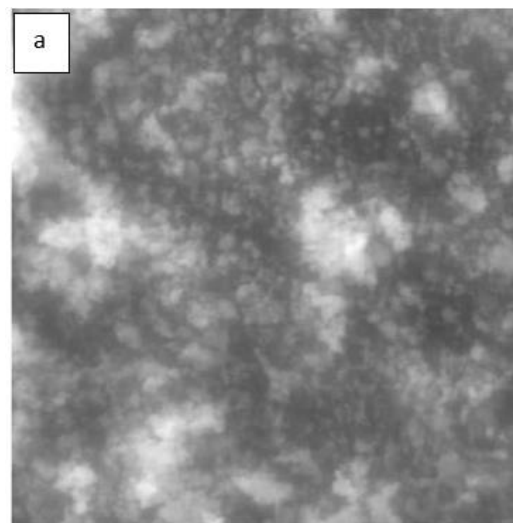


Figure 2. XRD patterns of, a. (PVA/PEG) blend, b. (PVA/PEG: ZnO & 1wt.% Co₃O₄), c. (PVA/PEG: ZnO & 2wt.% Co₃O₄), and d. (PVA/PEG: ZnO & 3wt.% Co₃O₄) nanocomposite films. [ZnO: hexagonal phase and Co₃O₄: cubic phase]

Scanning Electron Microscopic (SEM) Studies

The morphology of the pure metal oxides ZnO and Co₃O₄ NPs and nanocomposite film (PVA/PEG: ZnO and 3wt.% Co₃O₄) was investigated by SEM as shown in figure (3). From the image of SEM of pure ZnO and Co₃O₄ NPs, it is apparent that the substance is composed of small particulates, which aggregated as nonuniform clusters, which may be attributed to the nature of the NPs powders. This indicates that the ZnO and Co₃O₄ NPs are consisted of various uniform sized nanoparticles, and these particles are further aggregated to form porous agglomerate structures as in figure(3a,b). The surface image of polymer blend film displayed in figure(3c) indicates a homogeneous phase without phase separation, showing at this blend ratio the outstanding miscibility of PVA and PEG. The incorporation of 5 wt.% ZnO and 3 wt.% Co₃O₄ NPs into the optimum polymer blend film, as seen in figure(3d), shows good distribution and homogeneity in surface morphology, resulting in an improvement in break elongation. The performed film has not been found to be brittle and can simply



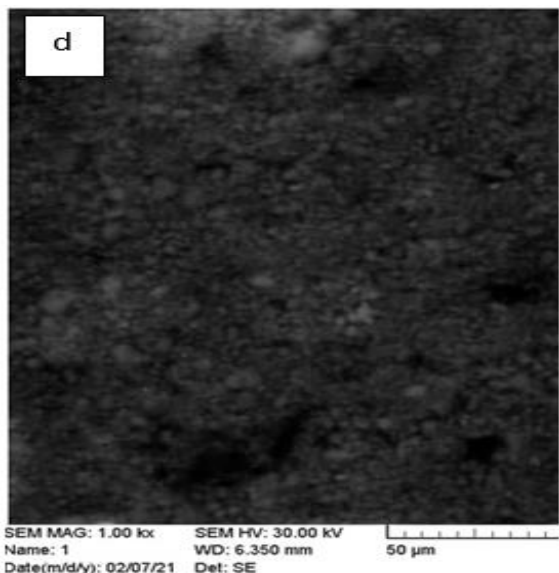


Figure 3. The images of SEM :(a,b) ZnO and Co₃O₄ NPs, (c) (PVA/PEG) polymer blend, and (d) PVA/PEG: ZnO & 3wt.% Co₃O₄ nanocomposite film

The D.C Electrical Properties of the Casting Samples D.C Electrical Conductivity of (PVA/PEG) Polymer Blend and its Nanocomposites

The D.C electrical conductivity σ_{dc} depends upon several factors such as the preparation technique, and the measurement conditions. Fig. (4) shows the

dependence of σ_{dc} on temperature T and both the ZnO & Co₃O₄NPs content for PVA/PEG films. the highest conductivity values, σ_{dc} (max), are 1.9×10^{-12} , 1.59×10^{-8} , 8.16×10^{-9} , and 1.27×10^{-6} (S/cm) for pure PVA/PEG, 1, 2, and 3 wt.% Co₃O₄ nanocomposite films, respectively. The increase of (σ_{dc}) with increasing the Co₃O₄ substance could be attributed to forming of linked networks in the polymer matrix on the other hand, both ZnO and Co₃O₄ are a semi-conducting materials and mixing with PVA/PEG may lead to the formation of energy levels inside the energy band gap, which serve as traps for charge carriers that moving between these levels through a hopping process, resulting in the increase of σ_{dc} (Divya et al., 2014).

In addition, Fig.(4) shows that, the σ_{dc} increases with increasing T. This indicates that these films are thermally activated and exhibit semiconductor properties. The segmental motion of polymer chains and the mobility of ZnO and Co₃O₄ NPs may be increased as T increases (Patil et al., 2012). As a result, the number of ionic charge carriers has increased because more ions have received kinetic energy from thermally activated hopping (Films et al., 2008). This habit is consistent with research findings (Hashim et al., 2018).

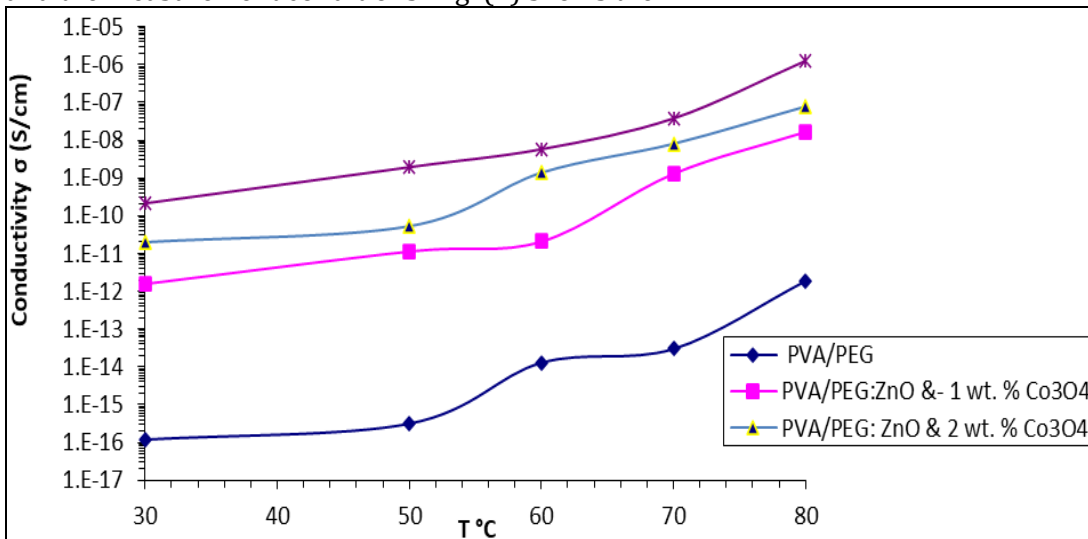


Figure 4. The dependence of DC conductivity(σ) of PVA/PEG films on both the ZnO & Co₃O₄ NPs content and temperature

Activation Energy of (PVA/PEG) Polymer Blend and its Nanocomposites

Fig. (5) shows the variation of $(\ln\sigma)$ versus reciprocal of the absolute temperature ($10^3/T$) measured at a temperature range (303 –353K) for polymer blend and its nanocomposites films with

ZnO and different ratios of Co₃O₄ NPs to calculate the activation energy using Arrhenius equation:

$$\sigma = \sigma_0 \cdot \exp(-E_{ac}/K_B T)$$

The calculated results of the electrical activation energy (E_{ac})values are ranging from 1.705 to 1.486 eV as display in table (2). The presence of free ions in the polymers was due to the high value of electrical activation energy for pure (PVA/PEG)



mix. The decrease of activation energies with the increasing of the nanoparticle's concentration in the nanocomposite films, related to increase the local energy levels in the energy gap which act as traps for charge carriers and that play a significant role in the charges transport (Divya et al., 2014). This behavior is in consistent with the results of researcher (Mishra & Aireddy, 2011).

Table 2. The experimental results of the electrical activation energy values

Samples	activation energy (eV)
PVA/PEG (blend)	1.705
PVA/PEG: ZnO & 1wt.% Co ₃ O ₄	1.656
PVA/PEG: ZnO & 2 wt.% Co ₃ O ₄	1.558
PVA/PEG: ZnO & 3 wt.% Co ₃ O ₄	1.486

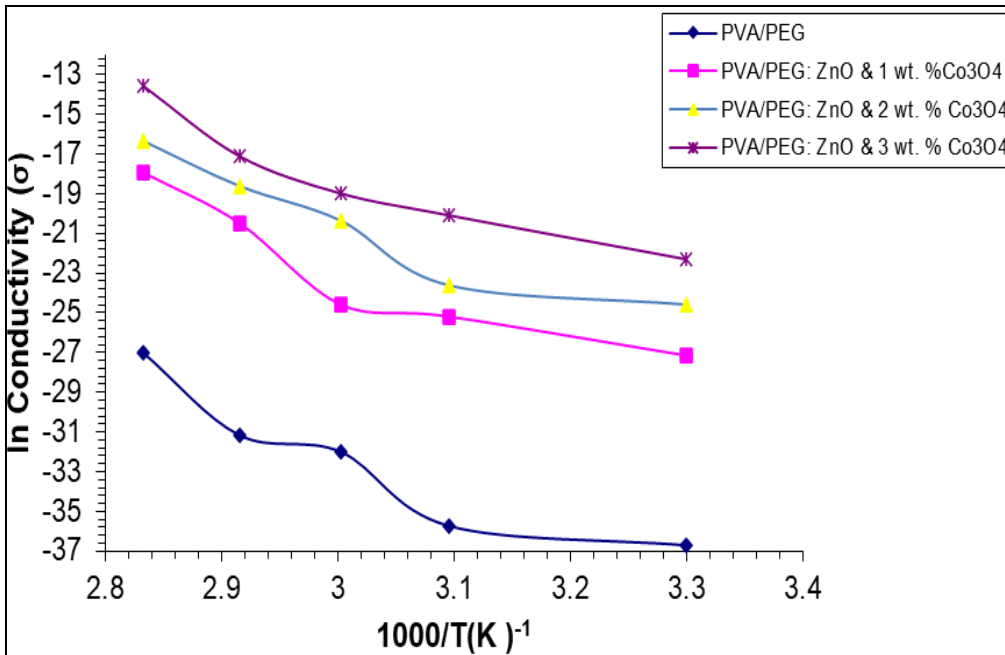


Figure 5. $\ln \sigma$ versus $(10^3/T)$ of (PVA/PEG) blend and its nanocomposite films with ZnO and different ratios wt.% of Co₃O₄

The A.C Electrical Properties of the Casting Samples

ZnO and Co₃O₄ NPs films were used to prepare and increase the transport carriers because the polymer blend PVA/PEG is an electricity insulation material. The A.C electrical properties of polymer blend and its nanocomposite films include: dielectric constant, dielectric loss and A.C electrical conductivity which were studied in the RT over the frequency range 10² -5×10⁶ Hz.

Dielectric Constant

The dielectric constant's magnitude denotes the material's ability to store energy from an applied electric field. The dependence of dielectric constant on electric field frequency range 10² -5×10⁶ Hz and

both the ZnO & Co₃O₄ NPs content for PVA/PEG films at RT shown in Fig. (6) Decreasing the dielectric constant with increasing electric field frequency is clearly shown in the ratio 3wt.% of Co₃O₄ NPs. This may be due to the tendencies of dipole in the samples for orienting themselves in the directions of the applied electrical fields and Space charge polarization is decreasing in relation to total polarization. At low frequencies, space charge polarization is the most important type of polarization, and as frequency increases, it becomes less important. The maximum dielectric constant, are 4.17, 3.47, 4.44, and 5.85 (S/cm) for (PVA/PEG), 1, 2, and 3 wt.% Co₃O₄ nanocomposite films at 100Hz, respectively. These are similar to the results of researcher (El Sayed & El-Gamal, 2015).



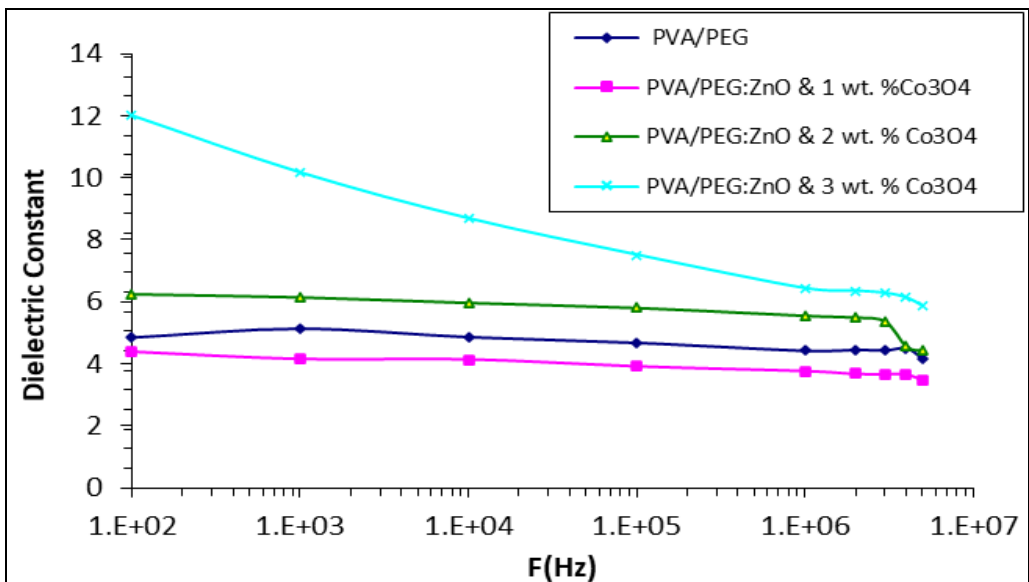


Figure 6. The dependence of dielectric constant of PVA/PEG films on both the ZnO & Co₃O₄ NPs content and frequency at RT

Dielectric Loss

The dielectric loss is a measurement of how much electrical energy is lost in the sample as a result of the applied field being converted to thermal energy. The dependence of dielectric loss on electric field frequency range $10^2 - 5 \times 10^6$ Hz and both the ZnO & Co₃O₄ NPs content for PVA/PEG blends at RT

shown in Fig. (7). The maximum dielectric loss, are 0.46 , 4.1×10^{-1} , 5.6×10^{-1} , and 7.9×10^{-1} for pure PVA/PEG, 1, 2, and 3 wt.% Co₃O₄ nanocomposite films at low frequency (100Hz), respectively, and decreases as the frequency of the applied electric field is increased. This is due to a decline in the contribution of space charge polarization.

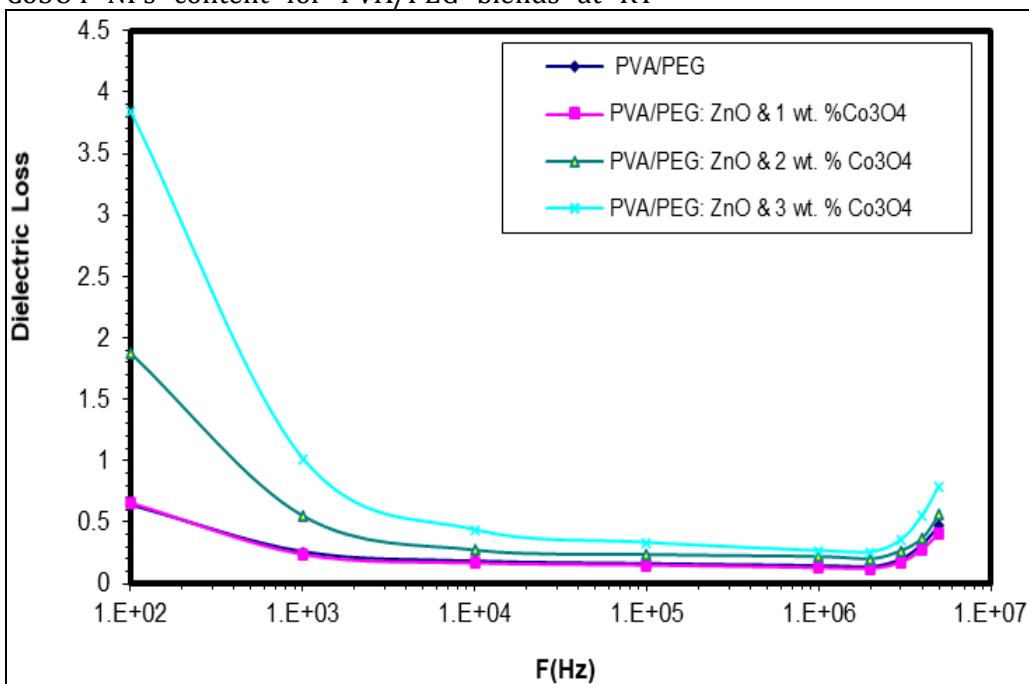


Figure 7. The dependence of dielectric loss of PVA/PEG blends on both the ZnO & Co₃O₄ NPs content and frequency at RT

A.C Electrical Conductivity

The dependence of A.C electrical conductivity on electric field frequency range $10^2 - 5 \times 10^6$ Hz and both the ZnO and Co₃O₄ NPs content for PVA/PEG films at RT shown in Fig. (8). For all samples, the

A.C conductivity increases significantly as the electric field frequency rises. This is due to space charge polarization, which happens at low frequencies, as well as the hopping motion of charge carriers (Hashim et al., 2018). Also the



conductivity increases with the increasing of the wt.% of Co₃O₄ NPs. This behavior is due to the effect of the space charge as a result of the increase the carriers of charge, due to the regular distribution in

the polymer matrix. This is in agreement with the results reached by the researcher (Habeeb et al., 2020).

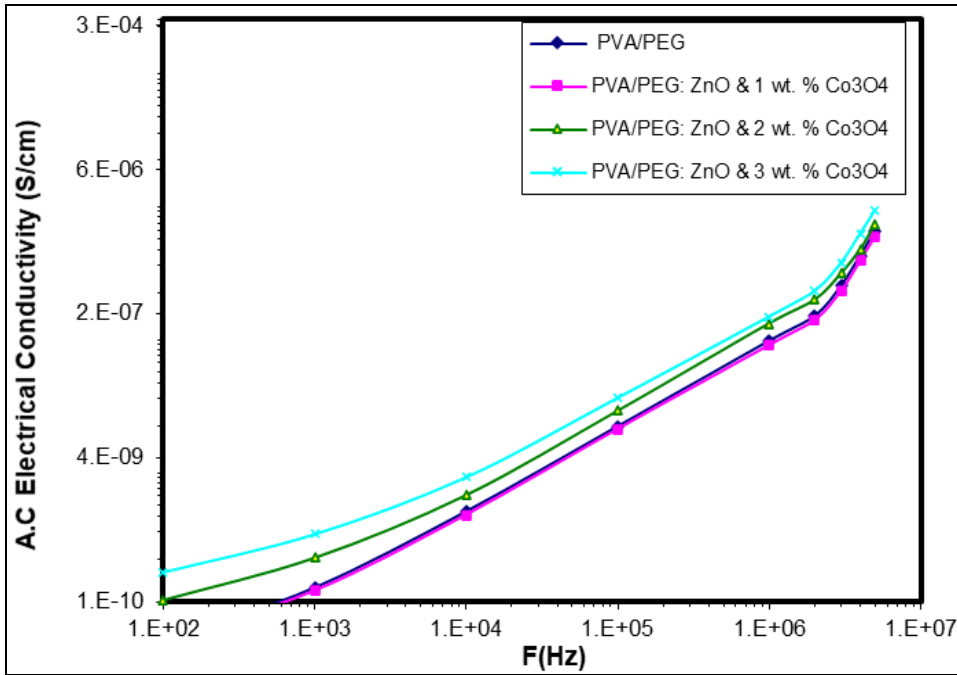


Figure 8. The dependence of A.C electrical conductivity of PVA/PEG blends on both the ZnO & Co₃O₄ NPs content and frequency at RT

Application of (PVA/PEG:ZnO & CO₃O₄) Nanocomposites for Gama Ray Shielding

Figure (9) depicts the variation of (N_0/N) for (PVA/PEG:ZnO) blend with various Co₃O₄ concentration. With the increasing of Co₃O₄ concentrations, transmission radiation decreases, which is attributed to an increase in attenuation radiation (Agool et al., 2017). Figure (10) depicts the variation in gamma radiation attenuation coefficients for (PVA/PEG:ZnO) blend as a function

of Co₃O₄ concentration. The attenuation coefficient increases as gamma radiation is absorbed or reflected by nanocomposites shielding materials. From the figures, When comparing the results obtained by polymer composite with concrete, it revealed very close results; however, nanocomposite polymer has an advantage over concrete due to its mobility, lower electrical properties, and ability to prevent neutron emission (Habeeb et al., 2017).

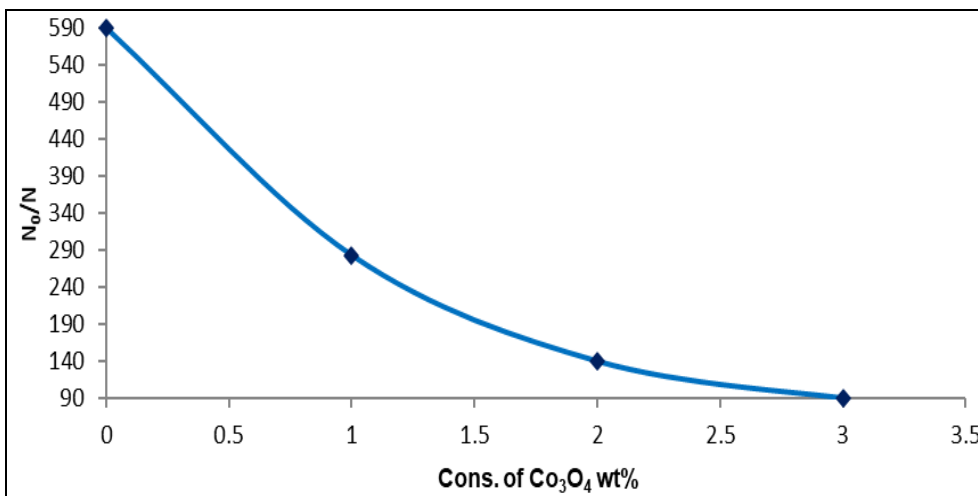


Figure 9. variation in (N_0/N) or (PVA-PEG-ZnO) blend as different concentrations in Co₃O₄



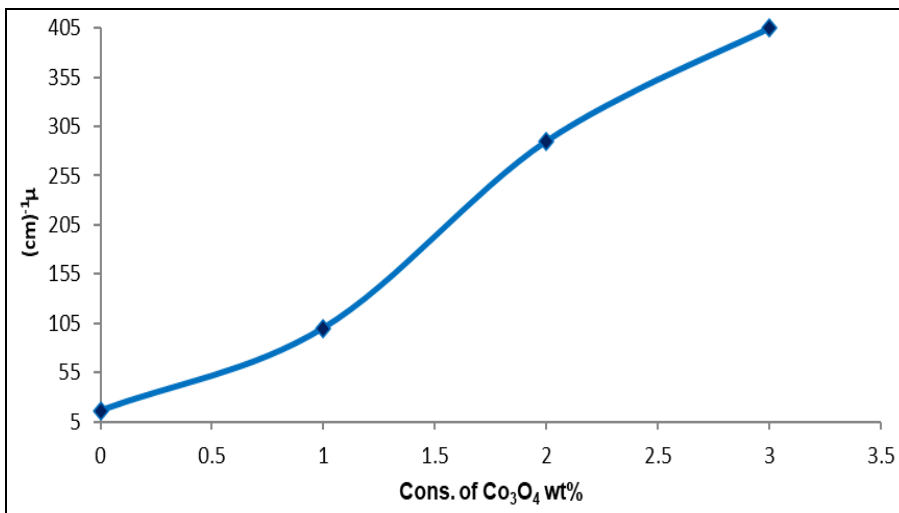


Figure 10. variation in attenuation coefficients in gamma radiation or (PVA-PEG--ZnO) blend as a function in Co₃O₄ concentrations

Conclusions

Polymer blend (PVA/PEG) and its nanocomposites with constant and different ratios of Co₃O₄ NPs films synthesized using solution cast technique. The FT-IR spectra confirmed of the produce the functional groups present in polymer nanocomposite systems. XRD analysis confirmed the formation nanocomposite films more crystalline from the polymeric matrix. SEM The images showed a powerful dispersion of ZnO and Co₃O₄ NPs on the surface of the polymeric matrix. D.C conductivity of the polymeric system increases with ZnO and various wt.% of Co₃O₄ for all temperatures under test. D.C measurements indicate that all films having one activation energy, and that its value increases with the increase in the percentage of addition. The AC electrical properties showed that the dielectric constant and dielectric loss for all different wt.% of Co₃O₄ particles decreases with the increase of the electric field frequency. The (PVA/PEG) and its nanocomposites have good linear attenuation coefficients for gamma ray radiation.

References

- Abdelamir AI, Al-Bermany E, Hashim FS. Important factors affecting the microstructure and mechanical properties of PEG/GO-based nanographene composites fabricated applying assembly-acoustic method. *AIP Conference Proceedings*, 2020; 2213(1): 020110.
- Agool IR, Kadhim KJ, Hashim A. Synthesis of (PVA-PEG-PVP-ZrO₂) nanocomposites for energy release and gamma shielding applications. *International Journal of Plastics Technology* 2017; 21(2): 444-453.
- Bilkan C, Altindal S, Azizian-Kalandaragh Y. Investigation of frequency and voltage dependence surface states and series resistance profiles using admittance measurements in Al/p-Si with Co₃O₄-PVA interlayer structures. *Physica B: Condensed Matter* 2017; 515: 28-33.
- Divya R, Meena M, Mahadevan CK, Padma CM. Formation and Properties of ZnO Nanoparticle Dispersed PVA Films. *International Journal of Engineering Research & Technology* 2014; 3(7): 722-727.
- El Sayed AM, El-Gamal S. Synthesis and investigation of the electrical and dielectric properties of Co₃O₄/(CMC+ PVA) nanocomposite films. *Journal of Polymer Research* 2015; 22(5): 1-12.
- Falqi FH, Bin-Dahman OA, Hussain M, Al-Harathi MA. Preparation of miscible PVA/PEG blends and effect of graphene concentration on thermal, crystallization, morphological, and mechanical properties of PVA/PEG (10wt%) blend. *International Journal of Polymer Science* 2018.
- Harun MH, Saion E, Kassim A, Hussain MY, Mustafa IS, Omer MAA. Temperature dependence of AC electrical conductivity of PVA-PPy-FeCl₃ composite polymer films, Iskandar Shahrim Mustafa2 and Muhd Ahmad Ali Omer2. *Malaysian Polymer Journal* 2008; 3(2): 24-31.
- Habeeb M, Hashim A, Hayder N. Fabrication of (PS-Cr₂O₃/ZnCoFe₂O₄) Nanocomposites and studying their dielectric and fluorescence properties for IR sensors. *Egyptian Journal of Chemistry* 2020; 63(Part 2): 709-717.
- Habeeb M, Hashim A, Hadi A. Fabrication of New Nanocomposites: CMC-PAA- PbO₂ Nanoparticles for Piezoelectric Sensors and Gamma Radiation Shielding Applications. *Sensor Letters* 2017; 15(9): 785-790.
- Hashim A, Agool IR, Kadhim KJ. Novel of (polymer blend-Fe₃O₄) magnetic nanocomposites: preparation and characterization for thermal energy storage and release, gamma ray shielding, antibacterial activity and humidity sensors applications. *Journal of Materials Science: Materials in Electronics* 2018; 29(12): 10369-10394.
- Liu P, Chen W, Liu C, Tian M. A novel poly (vinyl alcohol)/poly (ethylene glycol) scaffold for tissue engineering with a unique bimodal open-celled structure fabricated using supercritical fluid foaming. *Scientific Reports* 2019; 9(1): 1-12.
- Liu Y, Kim HII. Characterization and antibacterial properties of genipin-crosslinked chitosan/poly (ethylene glycol)/ZnO/



- Ag nanocomposites. *Carbohydrate Polymers* 2012; 89(1): 111–116.
- Mahendia S, Tomar AK, Chahal RP, Goyal P, Kumar S. Optical and structural properties of poly(vinyl alcohol) films embedded with citrate-stabilized gold nanoparticles. *Journal of Physics D: Applied Physics*, 2011; 44(20): 205105.
- Mishra SC, Aireddy H. Evaluation of dielectric behavior of bio-waste reinforced polymer composite. *Journal of Reinforced Plastics and Composites* 2011; 30(2): 134–141.
- Mohamed MB, Abdel-Kader MH. Effect of excess oxygen content within different nano-oxide additives on the structural and optical properties of PVA/PEG blend. *Applied Physics A* 2019; 125(3): 1-11.
- Nandi D, Ghosh AK, De A, Sen P, Ghosh UC. Fabrication, nanostructure evaluation, 3D electrical transport and electrochemical capacitance of PEDOT-Ti(IV)-doped iron(III) oxide nanocomposite. *Journal of Materials Science* 2014; 49(2): 776–785.
- Patil V, Joshi P, Chougule M, Sen S. Synthesis and Characterization of Co₃O₄ Thin Film. *Soft Nanoscience Letters* 2012; 02(01): 1–7.
- Sengwa RJ, Choudhary S. Structural characterization of hydrophilic polymer blends/montmorillonite clay nanocomposites. *Journal of Applied Polymer Science* 2014; 131(16): 1–11.
- Sheha E, Nasr M, El-Mansy MK. Characterization of poly (vinyl alcohol)/poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) polymer blend: Structure, optical absorption, electrical and dielectric properties. *Physica Scripta* 2013; 88(3): 035701.
- Vennela AB, Mangalaraj D, Muthukumarasamy N, Agilan S, Hemalatha KV. Structural and optical properties of Co₃O₄ nanoparticles prepared by sol-gel technique for photocatalytic application. *International Journal of Electrochemical Science* 2019; 14(4): 3535–3552.
- Radhi AH, Du EAB, Khazaal FA, Abbas ZM, Aljelawi OH, Hamadan SD, Almashhadani HA, Kadhim MM. HOMO-LUMO energies and geometrical structures effect on corrosion inhibition for organic compounds predict by DFT and PM3 methods. *NeuroQuantology* 2020; 18(1): 37-45.

