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## Application of irradiated EPDM rubber foam filled by sugarcane bagasse carbons for removing pollutants from wastewater

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**Abstract**

The release of industrial oily wastewater is hazardous to the environment. The irradiated foamed ethylene-propylene-diene monomer (EPDM) rubber filled with three types of carbons; carbon black (CB) as traditional filler, activated carbon(AC) and activated biochar(BC); AC and BC prepared from sugarcane bagasse (SCB) as an agricultural waste; for effective removal of soluble dye and insoluble oil was prepared to offer solutions to this problem. The main objective is to enhance and improve both the adsorption and absorption capacities of the EPDM rubber towards the pollutants' removal via the incorporation of various carbon fillers under different irradiation doses which reinforce the rubber's stability. The prepared samples were characterized by XRD, FTIR, and contact angle. It is found that 25 kGy is the best irradiation dose where the samples can exhibit high sorption performance, as the crosslink density and stability are significantly increased. The removal (%) of MB dye was 31.3, 90.2, 81.6, and 23.1 % for EPDM rubber, EPDM/AC, EPDM/BC, and EPDM/CB, respectively. While, the crude oil absorption capacities were 7.2, 9.9, 5.6, and 6.0 g/g for EPDM rubber, EPDM/AC, EPDM/BC, and EPDM/CB, respectively. These results highlight the efficiency of using waste-derived materials in developing composites for water treatment purposes.

**Keywords** Absorption; Crude oil; EPDM rubber; Ionizing Radiation; Methylene Blue dye;

### 1. Introduction

The existence of humans and animals depends heavily on water. It is becoming more and more crucial to address pollution issues like non-degradable oils and soluble dyes in the natural water cycle because as industry and technology advance, water sources will become significantly more polluted and destroyed [1,2]. Due to their high toxicity, low biodegradation, and carcinogenicity, dye effluents from a variety of dyeing industries, including dye synthesis, and the textile and cosmetics industries, are known to seriously pollute water supplies [3]. Furthermore, the enormous aromatic structure of methylene blue (MB) dye, which is extensively utilized in the leather, textile, paper, and apparel industries, renders it extremely stable and low-degradable under conventional treatments, posing a risk to human health and possibly causing cancer. Dye removal before discharge into the hydrosphere may therefore be particularly difficult [4–6].

On the other hand, frequent marine oil leak incidents represent a substantial waste of valuable, non-renewable mineral oils as well as long-term risks to marine life. Many techniques, including gravity separation, solidification, dispersion, bioremediation, burning, absorption, and skimming, have been developed to deal with crude oil spills. However, a lot of time, effort, and money are typically used in these procedures. Additionally, they are ineffective with low flow and high viscosity crudes [7,8].

According to Cui et al. 2022 [9] and Sun et al. 2022 [10], it is difficult for conventional wastewater treatment techniques even physical techniques; e.g. filtration and sedimentation; chemical; e.g. oxidation and coagulation; or biological; e.g. activated sludge; to treat all pollutants, especially oily wastewater that contains bacteria, organic solvents, and other contaminants [11], resulting in the incomplete removal with high operational cost. Therefore the sorption methods; adsorption and absorption; as a promising solution for wastewater treatment can be effectively used for the removal of dyes and crude oil pollutants.

According to Liu et al. 2023 [12] and Yin et al. 2023 [13], techniques for treating wastewater that contains oil, grease, and organic materials have therefore attracted attention from every sector. Because it is easy to use, inexpensive to run, very effective at removing colours and oils from surfaces, and produces no hazardous consequences, sorption technology—which includes the adsorption of dyes and the absorption of oil—is widely used [14]. Yet, the choice of appropriate sorbents has a significant impact on this procedure. According to Subhan et al. 2022 [15], the creation of an effective sorbent is a difficult undertaking for researchers who aim to employ cost-effective and straightforward methods.

Since irradiation is employed throughout the manufacturing process, irradiated foamed EPDM rubber has advantages over typical sorbent materials for wastewater treatment, including ease of use and environmental friendliness. Hassan and El-Nemr 2013 [16] prepared composites using sodium montmorillonite (Na-MMT) and Aswan clay (ASC), two different forms of clay, and gamma-irradiated EPDM rubber in a foam structure. These composites were employed as adsorbents for many kinds of

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dyestuffs from aqueous solutions, including basic, acid, reactive, and dispersion colours. The rubber composites loaded with Na-MMT and AS showed maximum adsorption of 42% for the basic dye and 28% for the acidic dye, respectively. It was shown that the irradiation dose of 50 kGy was the ideal dose for the removal of dyes for all rubber composites.

In this research, the novelty is the usage of the agricultural waste; sugarcane bagasse; as a raw material for AC and BC, which are used as a filler for EPDM composites. Therefore, the aim and the specific objectives of this work are; Firstly, to prepare the irradiated EPDM composites filled with AC, BC; and carbon black (CB) for comparison reasons. Secondly, to assess the adsorption of MB dye, and the absorption of the crude oil from aqueous solutions. Thirdly, to determine the change in the sorbent's efficiency according to the type of carbon filler and the dose of the irradiation.

## 1. Experimental

### 2.1. Materials

Ethylene propylene diene monomer (EPDM) rubber, with an ethylene content of 59% and 4.4% 5- ethylidene-2-norborene (ENB), as termonomer was supplied by Polimer Europa (Italy) under the trade name Dutral * TER 4049: Mooney viscosity (ML1+4, 125 °C). ZnO, Assay 98%, free alkali 0.12%, Chloride (Cl) 0.005% and sulphate 0.02% were supplied from Alpha Chemika, India. Stearic acid ($CH_3(CH_2)_{16}COOH$) is an extra pure grade with assay 99% and a melting point of 54 °C. 1,2-dihydro 2,2,4-trimethyl quinoline (TMQ) as an antioxidant was obtained from Intatrade Chemicals GmbH, Germany. Carbon black N 375 (Ash content % 0.75, Pour density, kg/m³ 345. Fines content, % 7, Sulfur content, % 1.1, and External surface area (STSA), 91 $m^2/g$) are supplied by Hebei LongHao Chemical Technology Co. The chemical foaming agent used in this work was azodicarbonamide (ADC) has a gas yield of 220 mL/g, decomposition temperature of 160 °C, and was supplied from Haihong Chemical, China. Sugarcane bagasse (SCB) collected from a sugarcane juice shop, in Cairo, Egypt. Crude oil from QARUN Petroleum Company (QPC), Cairo, Egypt, (Table (1) contains the physical properties of crude oil).

**Table (1): Physical characteristics of QARUN Petroleum Company crude oil**

| Properties | Method | Result |
|---|---|---|
| **Density @ 20 ˚C (g/cm$^3$)** | ASTM D-7042 | 0.8719 |
| **Kinematic viscosity @ 40 ˚C cSt** | ASTM D-445 | 6.85 |
| **Ash content, (wt. %)** | ASTM D-482 | Nil |
| **API gravity @ 60° F** | ASTM D-7042 | 30.64 |
| **Total Sulfur, wt. %** | ASTM D-4294 | 0.08 |

### 2.2. Preparation of activated carbon (AC) and activated biochar (BC)

AC was prepared from SCB as reported in our previous works [17]. In this method, the washed and dried SCB was immersed in conc. $H_2SO_4$ overnight at room temperature. Then, the sample was heated overnight at 200°C. After cooling to room temperature, it was washed with distilled water and immersed in $NaCO_3$ to eliminate any residual acid. After that, it was washed until pH 6 and dried at 105°C for 6 h. For the BC, SCB was milled and washed three times with deionized water, and then it was dried at 60 ℃ for 24 h. The dried milled SCB was put into the crucible and sealed with aluminium foil. Then, it was heated in a muffle furnace at 300 ℃ for two hours with a heating rate of 25 ℃/min to obtain SCB biochar. After cooling to room temperature, one gram of SCB biochar is put into 100 mL (2 M – KOH) solution and stood for 24 h. After that, it was washed with deionized water till reached a neutral pH. Finally, it was dried at 60 ℃ for 24 h. The obtained KOH-activated SCB biochar was expressed as BC [18].

### 2.3. Preparation of formulated samples

**Table (2**) exhibits the preparation of EPDM rubber composites at different compositions. The mixing of composites was done on a rubber two-roll mill. The ingredients were successively added as follows: ZnO, Stearic acid, TMQ, 30 phr (part per hundred part of rubber) from AC, BC or CB fillers, and finally 10 phr from foaming agent was added. To uniformly disperse the ingredients into the EPDM matrix, the mixing process was carried out for about 15 min at room temperature. After mixing the samples, they were hot pressed at about 160 °C, under 160 kg/cm$^2$ for 20 min into sheets of about ~ 1 mm thickness and frame dimension 20*30 cm.

**Table (2):** Formulations of rubber composites**.**

| **Content of mixes (phr*)** | | | | |
|---|---|---|---|---|
| **Sample NO.** | **EPDM rubber** | **EPDM+AC** | **EPDM+BC** | **EPDM+CB** |
| **EPDM** | 100 | 100 | 100 | 100 |
| **ZnO** | 5 | 5 | 5 | 5 |
| **Stearic acid** | 1 | 1 | 1 | 1 |
| **AC filler** | 0 | 30 | 0 | 0 |
| **BC filler** | 0 | 0 | 30 | 0 |
| **CB filler** | 0 | 0 | 0 | 30 |

*****phr: part per hundred parts of rubber.

### 2.4. Preparation of Samples for Irradiation

The masticated sheets that were ready were divided into slabs. One-millimetre sheets were covered on both sides with polyester sheets between two spotless, polished stainless-steel sheets. The sheets were then pressed in a Carver hydraulic hot press at 120 °C for a minimum of five minutes, with 160 kg/cm$^2$ of pressure applied to the mould surfaces.

### 2.5. Irradiation procedure

At the NCRRT, Cairo, Egypt, samples were irradiated using an electron beam accelerator (Energy 3 MeV, power 90 kW, beam current 30 mA, conveyer speed 16 m/min (50 HZ), and scan width changeable up to 90 cm). The rubber composites were subjected to varying dosages (25, 50, and 100 kGy) of electron beam irradiation at room temperature.

### 2.6. Characterization

XRD was used to check the crystal phases of the structure's samples at room temperature (Shimadzu XD-1 diffractometer, Japan). Fourier transform infrared spectroscopy (FTIR) was used to investigate the surface properties of the synthesized compounds (FTIR, Bruker, Unicom, Germany). Theta optical tensiometer (Biolin Scientific Company, Finland) was used to measure the contact angle (CA) between the prepared samples and water at 25 °C (298 K).

### 2.7. Soluble fraction (SF) and Swelling ratio (S)

The Soluble fraction (SF) of the produced irradiated, and un-irradiated rubber composite sheets were examined in which these composites were refluxed at 60 °C for 24 hours utilizing an appropriate solvent as toluene. The samples were removed after extraction and maintained for five hours in a fume hood before being dried to constant weights in an oven at 50 °C. Eq. (1) can be used to determine the soluble fraction:

$SF = W_o – W_1/W_o$ Eq. (1)

Where: $W_o$ and $W_1$ represent the original and final weights of the sample after extraction and drying respectively.

The prepared samples' swelling characteristics were investigated by weighing them again ($W_2$) after they had been ($W_1$) in a beaker filled with solvent for a whole day. The degree of swelling was then computed as follows. Here is how to find the swelling number (S):

$S = W_2 – W_1/W_1$ Eq. (2)

### 2.8. Water absorption

The following procedure was used to test the swelling behaviour in water: an insoluble composite ($W_i$) dry weight was soaked in water for 24 hours at room temperature. After that, the sample was taken out, the excess water on the surface was blotted off with filter paper, and the weight was again measured ($W_f$). The following formula was used to get the percentage of swelling:

Swelling (%) = $(W_f – W_i)/W_i \times 100$ Eq. (3)

### 2.9. Sorption studies and swelling

To calculate the percentage of methylene blue dye removed by adsorption, a certain concentration of MB dye (10 ppm) was first prepared. Subsequently, the dye solution was immersed with a constant weight of the produced composites, and the uptake by these composites was ascertained by measuring the light absorption of the leftover dye solution at $\lambda_{max}$ = 664 nm using a UV/Vis spectrophotometer (JENWAY–6505). The following formula was used to calculate the percentage of dye adsorption removed by the composites that were made:

Removal (R %) = $(C_i – C_f)/C_i \times 100$ Eq. (4)

Where (R %) is the removal percentage representing the adsorption efficiency, $C_i$ and $C_f$ are the initial and final MB dye concentrations, respectively.

The ability of the prepared composites to absorb crude oil pollutants was measured using the gravimetric technique. The starting weight of the sample ($m_i$) is precisely measured and submerged in the crude oil sample for 24 h after a glass beaker containing crude oil diluted by toluene (ratio-1:3) is prepared. The foam sample is taken out of the beaker and promptly weighed ($m_f$) after the absorption process is finished. The absorption capacity Q (g/g) of the absorbent can be determined using the subsequent formula:

Q (g/g) = $(m_f – m_i)/ m_i$ Eq. (5)

Crude oil can enter the network structure by immersion, which causes an increase in sorbent volume—a phenomenon commonly referred to as swelling. The following formula was used to determine the swelling ratio of the produced samples:

Swelling ratio (%) = $(m_f – m_i)/ m_i \times 100$ Eq. (6)

## 2. Results and discussion

### 3.1. Structure and wettability analysis

#### 3.1.1. XRD analysis

Fig. (1) represents the XRD spectra of irradiated EPDM and its composites loaded by AC, BC, and CB. The XRD pattern of EPDM and its composites involved a broad peak for amorphous rubber structures with a centre at 2θ around 20°. Moreover, three characteristic peaks of the hexagonal structure of ZnO were observed at 32°, 35° and 36° [19]. Also from this figure, it is observed that the XRD peak at the specified 2θ decreases from EPDM to EPDM composites (especially for EPDM/BC) due to decreasing order of crystallinity by physical crosslinking due to the incorporation of filler [20].

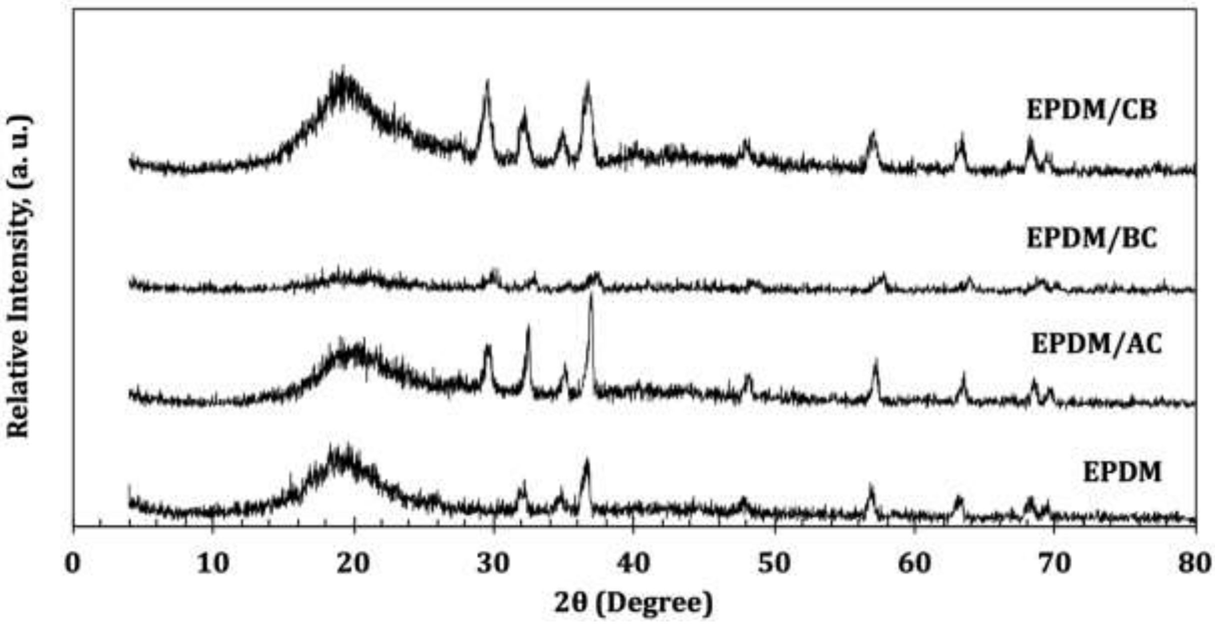


**Fig. (1).** XRD spectra of EPDM and EPDM composites loaded with 30 phr of AC, BC, or CB (irradiated at 25 kGy).

### 3.1.2. FTIR analysis

The FTIR spectroscopy of irradiated EPDM and its composites loaded by AC, BC, and CB is displayed in **Fig. (2**). The EPDM distinctive bands observed at 2925 and 2843 $cm^{-1}$ are related to the asymmetric stretching of the C–H. The band at 1460 $cm^{-1}$ is due to significant angular vibration of $–CH_2$, the band at 1374 $cm^{-1}$ is ascribed to CH deformation in the $–CH_3$ group. The CH deformation in C–($CH_3$) is identified by the band at 1144 $cm^{-1}$. Unsaturation 5-ethylene-2-norborene (ENB) exhibited its characteristic peaks at 1683 $cm^{-1}$ and 809 $cm^{-1}$. The Band appeared at 722 $cm^{-1}$ corresponding –($CH_2$)– stretching [21]. The FTIR spectra for EPDM loaded by AC show the same peaks as EPDM, but a new peak that appeared at 1545 $cm^{-1}$ is due to the C–O stretching vibration of carbon species [22]. The increase in the peak band at 1050 $cm^{-1}$ in the spectra of EPDM by adding BC samples is related to the carbon fingerprint and is related to the C–O symmetric and asymmetric stretching vibration of –C–O–C– ring. The FTIR spectra for EPDM loaded by CB show a band at 3361 $cm^{-1}$ is related to the presence of a very small amount of H–bonded phenolic –OH groups in the developed rubber composites, the band at 1450 $cm^{-1}$ is due to Asymmetric C–O stretching of phenols of CB [23]. The peak at 1630 $cm^{-1}$ was only observed for pristine CB, which is ascribed to the C=C stretching vibration present in the material, the band at 1052 $cm^{-1}$ observed for CB can be attributed to C−O stretching [24].

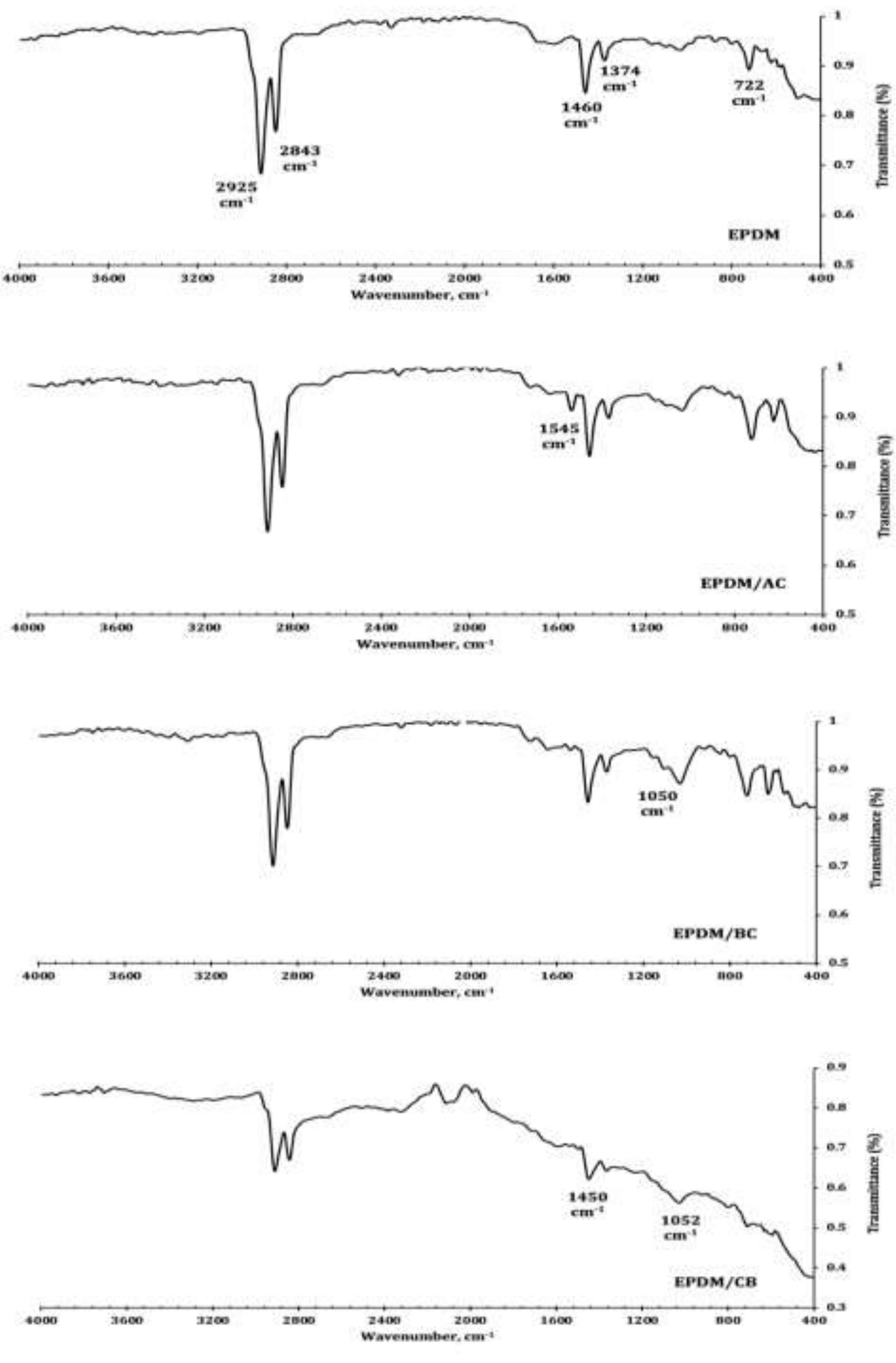


**Fig. (2).** FTIR spectra of EPDM and EPDM composites loaded with 30 phr of AC, BC, or CB (irradiated at 25 kGy).

### 3.1.3. Wettability analysis

**Fig. (3)** shows the contact angles between water and the prepared samples, EPDM and EPDM composites with different carbons as fillers. It can be observed that the water produced a droplet with a larger contact angle, indicating less wetting of the surface EPDM/AC has the highest contact angle value (99.16°) than the other samples which means it has a more hydrophobic surface. Also, this may be due to the presence of AC type in EPDM rubber composite resulting in a highly porous material with a large surface area . The activation process forms a network of pores and increases the surface area available for adsorption. EPDM/AC sample exhibited the largest contact angle than EPDM alone and EPDM/BC, meaning that the surface of EPDM/AC could be more hydrophobic (repels water) or oleophilic (attracts oil) than the others [25].

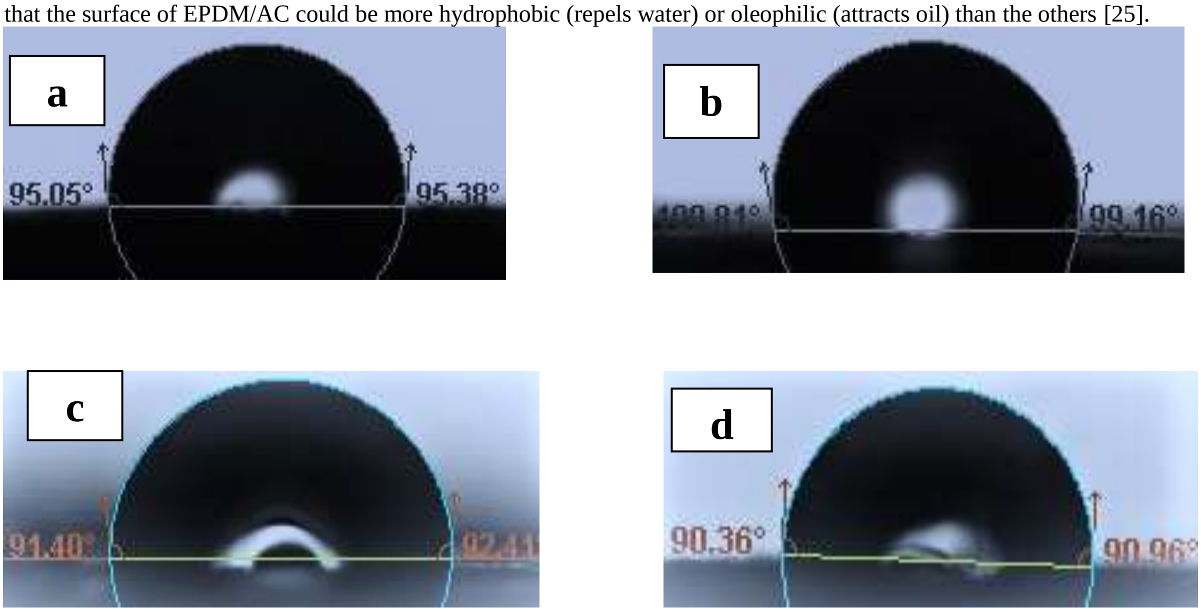


**Fig. (3).** The contact angles for the prepared samples, (a) EPDM rubber (b) EPDM/AC, (c) EPDM/CB and (d) EPDM/CB at 25 kGy.

The dose of irradiation can also influence the contact angle between water and modified rubber. **Fig. (4)** shows the contact angle of EPDM/AC at different doses of irradiation (25, 50, 100 kGy) it can be observed that the contact angle value increases at dose 25 kGy (99.16) and by increasing the dose it decreases (at 50 kGy, 93.12° and at 100 kGy, 89.35°), this may be due to the irradiation dose, as the exposure of a material to ionizing radiation, such as gamma rays or electron beams. This process changes the surface properties of materials and their morphology; it can increase or reduce surface energy, influencing wetting behaviour and contact angle [26,27]. Also, irradiation can cause chemical alterations to the surface of modified rubber. Ionizing radiation can disrupt molecular bonds, resulting in reactive species that can react with the carbon surface. These chemical changes can alter the surface chemistry and, as a result, the contact angle. Irradiation can cause crosslinking and polymerization events on the activated carbon surface. This may result in the creation of a polymer layer or a more compact structure. The existence of such a layer can affect the contact angle by modifying surface roughness or establishing new surface chemistry. The data showed that changing the kind of carbon and the dose of irradiation changes the contact angle value.

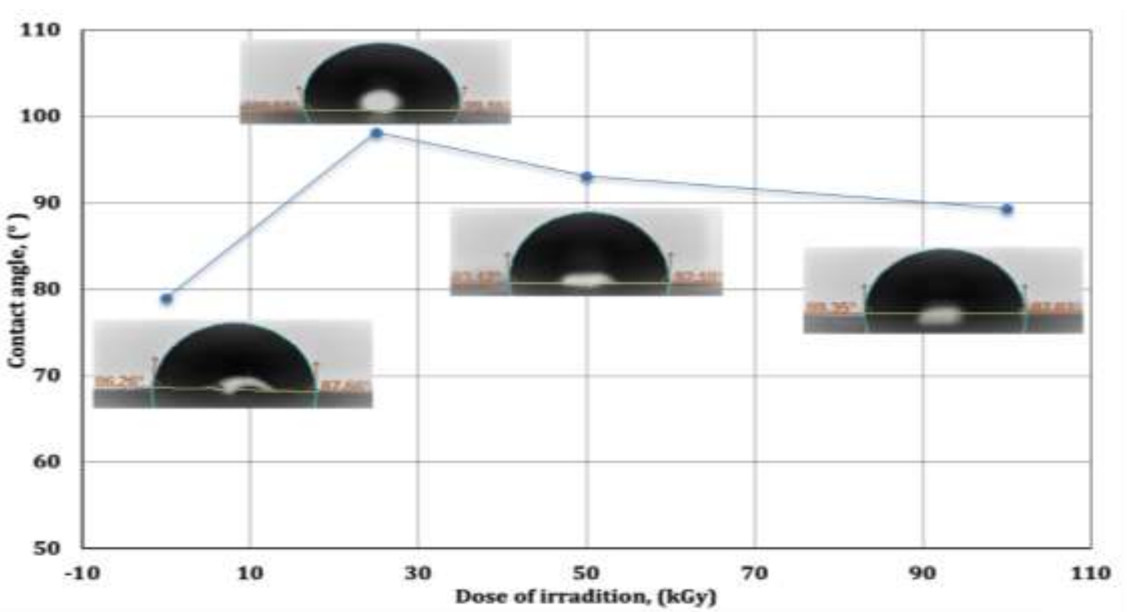


**Fig. (4).** Contact angle of EPDM/AC at different doses of irradiation (0, 25, 50, 100 kGy).

### 3.2. Soluble fraction and swelling ratio

The soluble fraction and number of swelling in toluene for Foam EPDM loaded with AC, BC, and CB vary with irradiation dose, as shown in **Fig. (5)**. The findings show that the values of the soluble percentage and swelling number for each sample gradually decrease when the radiation dose is increased. These findings are explained by the enhanced cross-linking in the samples brought on by exposure to ionizing radiation, which made it more difficult for the solvent to diffuse through the films. The findings also show that the percentage of soluble components and the number of swells were decreased in the samples treated with activated carbons. As a result, the solvent diffuses less across the substance. According to Khozemy et al. 2023 [28] and El-Nemr et al. 2011 [29], the soluble percentage decreases as the radiation dose increases, for the same reason—an increase in cross-link density.

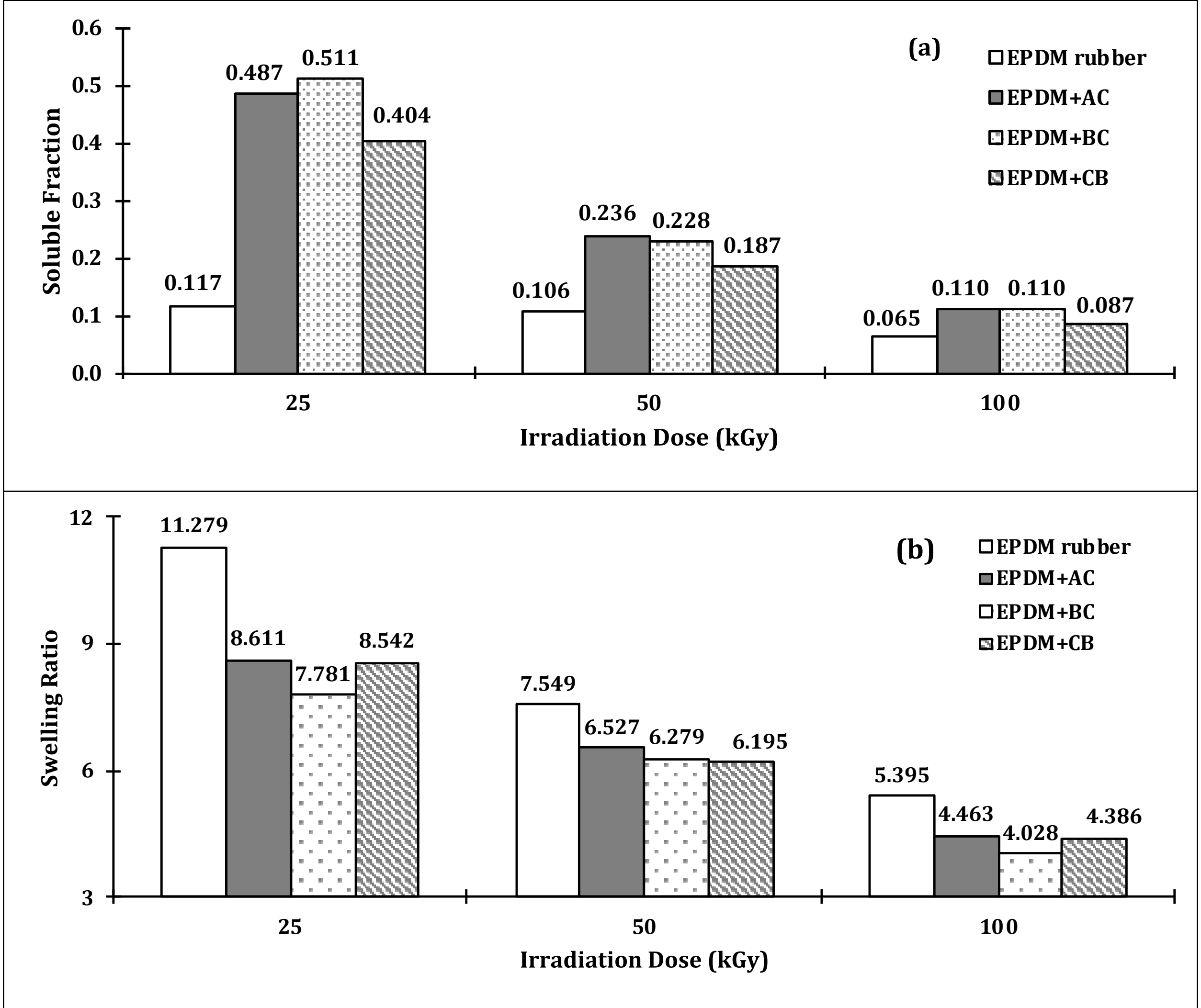


**Fig. (5).** Effect of irradiation dose on the soluble fraction (a) and swelling ratio (b) of EPDM rubber composites filled with different types of carbons.

### 3.3. Water absorption

The effect of irradiation dose on water absorption (%) after 24 h for different foamed EPDM rubber filled with AC and BC prepared from sugarcane bagasse and CB is shown in Fig. (6. It can be seen that the source of carbon materials; agricultural waste or carbon black; and the preparation method; activated carbon and activated biochar; which is used as filler for irradiated foamed EPDM rubber play a vital role in the water absorption behaviour, regardless the irradiation dose. For foamed EPDM rubber without any carbon fillers, the values of water absorption decreased with increasing the irradiation dose, due to the increased crosslinking by radiation. This increased crosslinking intern enhances the structural integrity of the rubber which limits its water absorbability. On the other hand, for foamed EPDM rubber with carbon fillers, the swelling is increased by irradiation till it reaches 25 or 50 kGy and then decreases, this behaviour may be due to the presence of carbon as fillers, these carbon materials possess high sorption capacity [30]. Among these composites, the EPDM/AC composite exhibited the highest water absorption (%) under 25 kGy, due to the increased porosity and hydrophobicity introduced by AC. For EPDM/BC composite, the water absorption is moderate, this limited performance may be due to the lower properties of BC than AC. Contrary to the EPDM/AC, the EPDM/CB, exhibits the lowest water absorption under all irradiation doses, due to the hydrophobic nature of CB resulting in minimal water uptake.

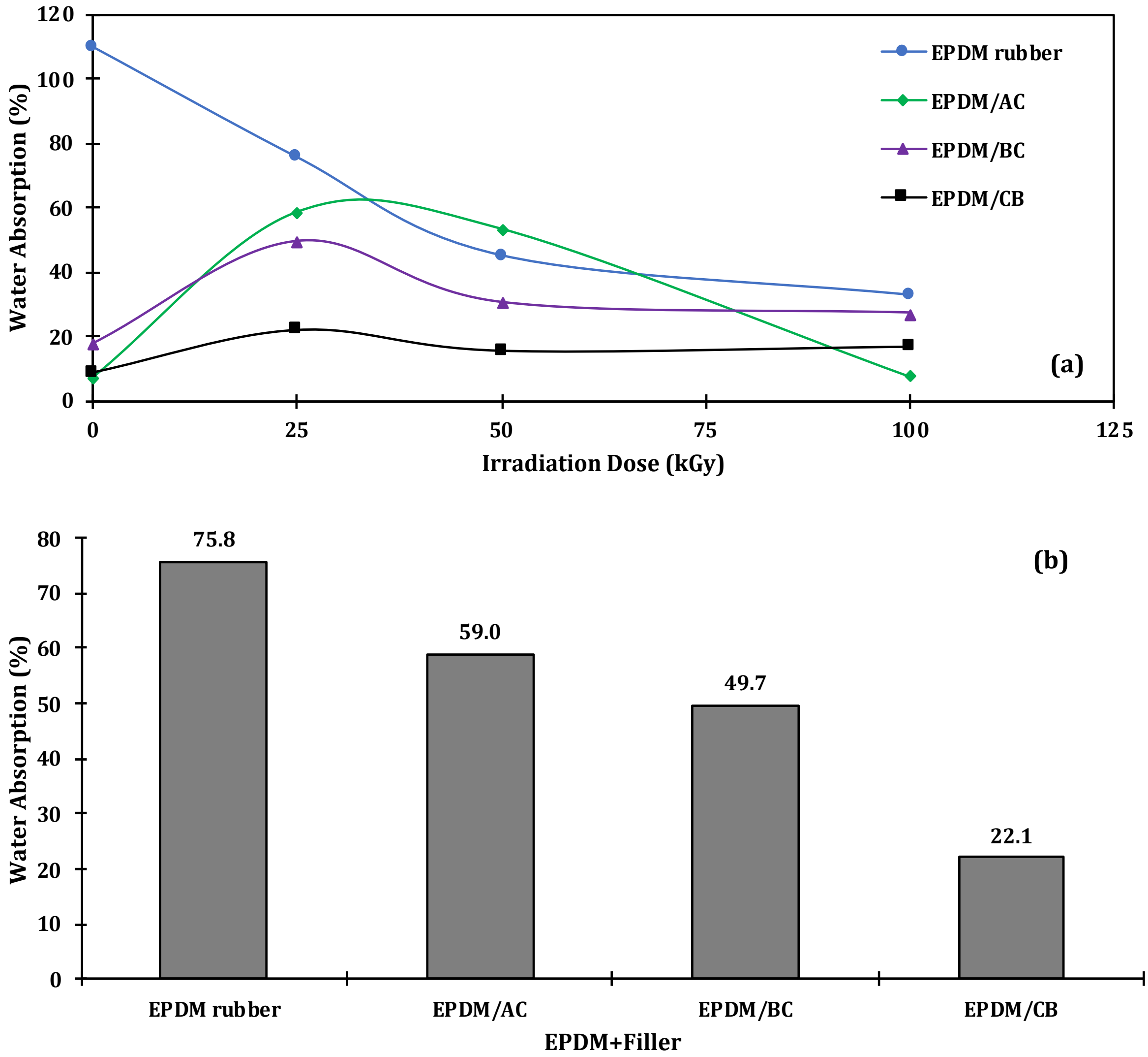


**Fig. (6).** (a) Effect of irradiation dose on the water absorption (%) after 24 h for foamed EPDM rubber filled by activated carbon (AC) and activated biochar (BC) prepared from sugarcane bagasse and carbon black (CB). (b) Effect of different fillers on the water absorption (%) after 24 h for foamed EPDM rubber composites at 25 kGy.

### 3.4. Removal of soluble and insoluble pollutants

#### 3.4.1. Effect of different carbon fillers on the sorption capacity of the foamed EPDM rubber

The effect of different carbon fillers on the sorption capacity of the irradiated (25 kGy) foamed EPDM rubber towards the adsorption of MB dye (10 ppm), Fig. (7a), and absorption of crude oil, Fig. (7b), after 24 h were examined. It was found that the adsorption percentages of MB dye by irradiated foamed EPDM rubber composites were 31.3% for blank EPDM and 90.2%, 81.6%, and 23.1% for EPDM filled by AC, BC, and CB, respectively. The crude oil absorption capacities were 7.2 g/g for blank EPDM and 9.9, 5.6, and 6.0 g/g for EPDM filled by AC, BC, and CB, respectively. From Fig. (7), it can be concluded that the irradiated foamed EPDM rubber composite filled by AC gave the highest MB dye adsorption and crude oil absorption.

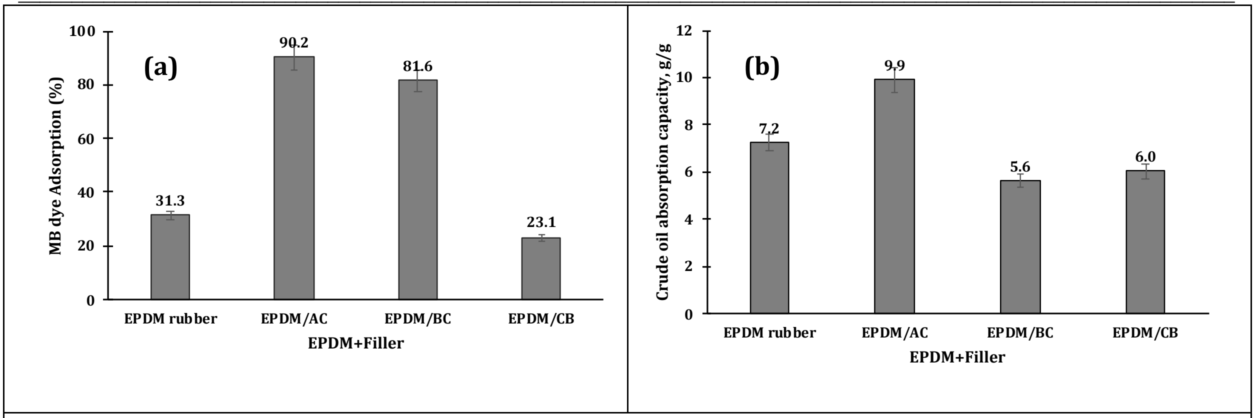


**Fig. (7).** Effect of different carbon fillers on the sorption efficiency of irradiated (25 kGy) foamed EPDM rubber towards MB dye (a) and crude oil (b) after immersion for 24 h.

### 3.4.2. Effect of irradiation dose on the sorption capacity of the foamed EPDM rubber

Using various foamed EPDM rubber composites filled with AC, the effect of the irradiation dose on the sorption of crude oil and MB dye was investigated, as illustrated in Fig. (8). The results indicate that the irradiation dose had an impact on both the crude oil absorption (Fig. (8b) and the dye adsorption (Fig. (8a). No matter the kind of pollutant or carbon filler used, the dye and oil sorption decreased as the irradiation dose applied to these composites increased up to 100 kGy. The reason behind both dye and oil sorption could be ascribed to the impact of irradiation doses on the swelling of the rubber composite. The rubber composites' increased crosslinking at higher irradiation doses results in a decrease in the swelling ratio and a subsequent decrease in the pollutant sorption. The optimal irradiation dose, as determined by Fig. (5), Fig. (6), and Fig. (8), was found to be 25 kGy. This dose also improved the soluble fraction and swelling ratio of various EPDM rubber composites that were used. It also gave good dye adsorption efficiency and crude oil absorption capacity.

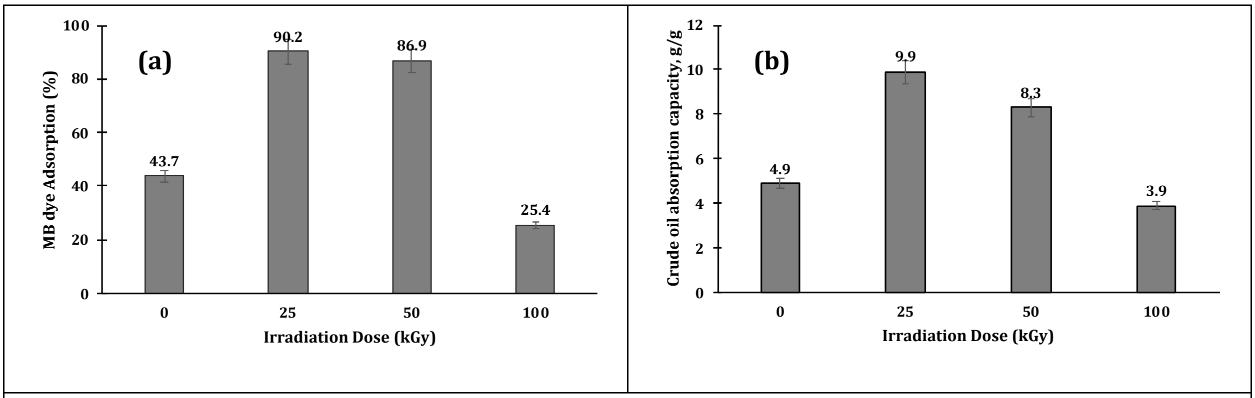


**Fig. (8)** Effect of irradiation dose on the sorption efficiency of foamed EPDM rubber filled by AC towards MB dye (a) and crude oil (b) after immersion for 24 h.

The suggested adsorption mechanism for the different pollutant types; soluble MB dye and insoluble crude oil; on the irradiated foamed EPDM rubber composites are affected by various parameters mainly the adsorbent properties and the pollutant type or nature. Regarding the adsorbent properties, the variation in the irradiation dose can enhance the removal efficiency of the composites toward pollutants removal by creating extra crosslinking and additional reactive sites in the composites till reaching a specific irradiation dose; in our case, it is 25 kGy; after this point, the removal efficiency decreased. Also, the presence of the carbonaceous materials; AC or BC; as a filler enhances the specific surface area and the porosity of the composites, facilitating the interaction between the composites and the pollutants. The swelling behaviour can also affect the removal performance of the prepared composites. As the composite swells in the pollutant solution, it facilitates the penetration of pollutant molecules; dye or oil; which in turn enhances the overall removal behavior.

## 4. Conclusion

In order to effectively remove both soluble dye and insoluble oil contaminants, this article examined the use of waste-based materials in EPDM rubber composites loaded with several forms of carbon (AC, BC, and CB) under varying irradiation doses. The soluble fraction and swelling ratio findings showed that the crosslink density for all foamed EPDM rubber filled by carbon materials composites increased with increasing irradiation dose. The foamed EPDM rubber's behavior toward the adsorption of MB dye and the absorption of crude oil was improved by the use of carbon materials as fillers. The results showed that the irradiation dose at 25 kGy was the optimum for the removal of soluble dyes and insoluble crude oil. For EPDM/AC composite irradiated at 25 kGy, the MB removal % and crude oil absorption capacity were 90.2 % and 9.9 g/g, respectively. Mostly, the sorption of dyes and crude oil increased with increasing the contact time. From the current study, the irradiated foamed EPDM rubber composites with agricultural waste-based AC and BC have significant implications for sustainable wastewater treatment, resources recovery, and hence health protection by enhancing the removal of the different pollutants, contributing to achieving the sixth goal of the SDGs; clean water and sanitation. The utilization of waste-derived materials for wastewater treatment is an advantage of our studies over earlier research. Future research must optimize the composites, look into their reusability, and carry out more field investigations in order to increase their effectiveness and suitability for environmental remediation and evaluating the effectiveness of soil remediation or air purification as well.

**Declarations**

**Ethical Approval:** The manuscript is prepared in compliance with the Publishing Ethics Policy.
**Consent to Participate:** not applicable.
**Consent to Publish:** not applicable.

**Author Contribution**

*Enas Amdeha*: Conceptualization, Methodology, Carbon Synthesis, Characterization, Water treatment application, Data interpretation, Writing – original draft, editing & reviewing.
*Hamdi Radi*: Conceptualization, Methodology, Investigation, Polymer composites synthesis, Characterization, Data interpretation, Writing – original draft, editing & reviewing.
*Khaled F. El-Nemr*: Conceptualization, Methodology, Investigation, Polymer composites synthesis, Characterization, Data interpretation, Writing – original draft, editing & reviewing.
*Amira E. El-Tabey*: Conceptualization, Methodology, Characterization, Data interpretation, Writing – original draft, editing & reviewing.

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**Competing interest**: The authors declare no conflict of interest.
**Availability of data and materials:** All obtained data during this work are included in this manuscript.

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