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Studying Dosimetric Behavior of Orange IV Radiochromic Film for Radiation Dose Monitoring

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A THIN plastic film consisting of poly vinyl alcohol (PVA) and P^H indicator dye, Orange IV, in the presence of chloral hydrate was prepared and formed by simple casting technique. Studying its dosimetric behavior was executed to approve the possibility of its usage in dose monitoring, the data obtained reveal that the intensity of the absorption band at 448 nm was decreased with the increase of the absorbed dose in a systematic manner that covers a range that reaches up to 100 kGy. On visual investigation, the film changes its color from yellow to red passing through the orange color upon exposure to gamma rays. The response of the prepared films depends on both chloral hydrate and dye concentrations. Increase in recording values was noticed on increasing the concentrations of both the chloral .hydrate and dye. Although the film has a good stability in relative humidity ranging from 10% to 50% , correction should be done out of this addressed range. The film also has excellent stability before and after irradiation in different storage environments.

Keywords: Dosimetry, Orange IV dye, Radiation.

Introduction

Radiation dosimetry is compulsory in all radiation applications to obtain products with desired properties (Gafar & El-Ahdal, 2015; Gafar et al., 2017). Moreover, dosimetry science is used to measure the absorbed radiation dose, or determine the incident radiation on a material (Rabaeh et al., 2021). Therefore, it is necessary to ensure the accuracy of the radiation dose (Hosni et al., 2013; Raouaf et al., 2018). Colored thin plastic films have been used as dosimeters for measuring the adsorbed radiation dose, and have been applied in routine dosimeters (Kattan et al., 2011). The main technical advantage of a polymer film-based dosimeter as a radiation detector is its slightness and portability (Akhtar et al., 2016). In addition, the film has long storage stability and is cost-effective (Akhtar et al., 2013).

PVA-based polymer materials are most recommended because they have a high degree of flexibility (Ang et al., 2020), are water-soluble (Wong et al., 2020), have good mechanical properties, are non-toxic and elastic (Chaturvedi et al., 2015). For routine dose monitoring in radiation processing, the polymeric dyed flexible films are considered to be the most common ones as dosimeters, dose labels (Abdel-Rehim et al., 1985, 1990; Abdel-Rehim & Abdel-Fattah, 1993). These dyed poly (vinyl alcohol) PVA systems are bleached or change their color by irradiation aimed to determine the absorbed dose. A novel radiation-sensitive indicator consisting of poly (vinyl alcohol) film containing P^H dye and water-soluble chlorine-containing substance has been developed (Abdel-Fattah et al., 1996). Film dosimeters made from PVA dyed with methylene blue (MB) is prepared to be used in processes where high dose of gamma radiations are involved (Akhtar et al., 2013). Many other films containing a radiation-sensitive pH indicator dye with chloral hydrate have been prepared to be used as γ-radiation monitoring dosimeters and labels (Soliman, 2005). Recently, a new dosimeter is prepared by mixing poly

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vinyl alcohol (PVA) with trichloroethylene (TCE) in the presence of Cresol red for potential application in the determination of low doses (Doyan et al., 2021)

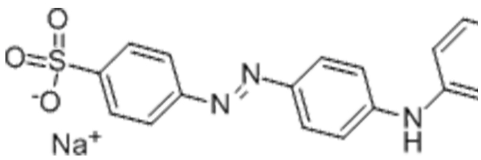
In the present study, an attempt has been made to characterize the effect of the absorbed irradiation doses on the PVA- Orange IV films to evaluate their dosimetric behavior in radiation processing.

Experimental

Preparation of stock dye solution of Orange IV

Stock solution of the Orange IV dye was prepared by dissolving 0.1 gm of the dye "product of Sigma Aldrich" in 50 ml distilled water.

The structure of Orange IV is shown in Scheme 1



Scheme 1. Structure of Orange IV

Preparation of Orange IV/PVA film

Orange IV/PVA films were prepared by dissolving 8.75 gm of PVA powder (average MW= 25000) fully hydrolyzed (99-100%) product of (G.t baker chemical CO.USA) in 175 ml double distilled water at about 60˚C, the solution was kept and well stirred for about 48 hr, then left to cool. Seven equal volumes of PVA solution were taken and the following additives were prepared:

- Firstly, adding in the first flask only 2 ml orange IV

- Secondly, studying the effect of different concentrations of chloral hydrate was executed through adding (0.1, 0.15, 0.2 g) of (CH) on the 2nd, 3rd and 4th flask containing 2 ml of the dye.

- Thirdly, studying the effect of different concentrations of dye (1 ml, 2 ml, 3 ml) and 0.2 C.H (chloral hydrate) was added in the last remaining three flasks.

After preparing the seven flasks, they were kept well stirred at room temperature for about 3hr in order to obtain the required homogeneous mixed solutions. Each solution was poured on a 15x15 cm^3 horizontal glass plate, left to dry at room temperature for about 48 hr. After drying, the films were stripped off from the glass plate, then cut into 1x1 cm^2 pieces, and stored for further investigation. The thickness of the obtained films was found to be 0.05± 0.005 mm (1δ).

Apparatus

The absorption spectra of the unirradiated and irradiated films were measured throughout the wavelength range (200-800 nm) using a UVKON 860 spectrophotometer. The film thickness was measured using a Digitrix-Mark thickness Gauge (precision≠1um; 1δ).

Irradiation was carried out with gamma rays using Gamma cell-220 Excel ^{60}Co irradiation facilities (Manufactured by MDS Nordian, Canada). The absorbed dose rate in water was measured by Frike dosimeter and was found to be 2.35 kGy/h. The temperature during gamma ray irradiation was 30^{0}C, and the electronic equilibrium conditions were maintained during irradiation by keeping the films between two polystyrene slabs of 3mm thickness.

Results and Discussion

UV/VIS absorption analysis

The absorption spectra of PVA film containing 0.32 phr of Orange IV dye without chloral hydrate were recorded before and after irradiation to different doses as shown in Fig. 1. The absorption spectra show a main absorption band in the visible region at 448nm. The intensity of this band decreases gradually upon exposure to Gamma rays. The color changes from yellow to faint yellow, this may be due to limited breakage that takes place in chromophore groups. By adding chloral hydrate, the behavior of the dye was changed, this was correlated with the change in medium acidity. Figure 2 indicates the absorption spectra of Orange IV/PVA film containing 0.32 phr of dye and 8 phr of chloral hydrate. Upon irradiation, the color of the film changes from yellow to red. The main peak at 448 nm decreases gradually by irradiation and shoulder begins to appear starting from 50 kGy absorbed dose at 575 nm. The intensity of this shoulder slightly increases due to the gradual transformation of orange IV into its acidic form.

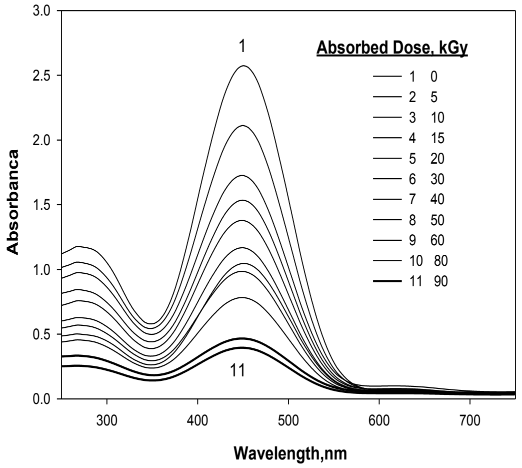


Fig. 1. The absorption spectra of Orange IV/PVA without chloral hydrate for un-irradiated and irradiated films to different absorbed doses [Orange IV]=0.32 phr

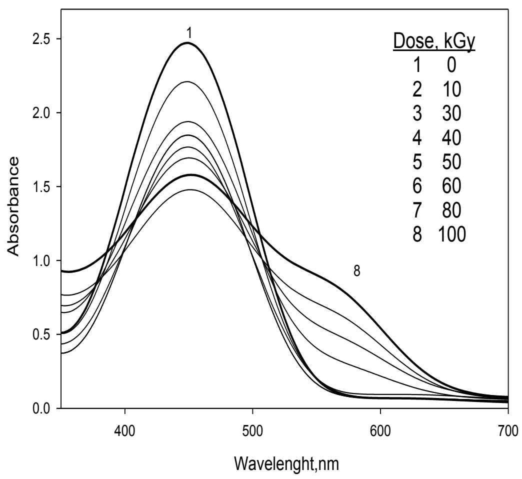


Fig. 2. The absorption spectra of Orange IV/ PVA containing chloral hydrate for un-irradiated and irradiated films to different absorbed doses [Orange IV]=0.32 phr, [Chloral hydrate]= 8 phr

Effect of different concentrations of dye on the response curve

The Response curve illustrated the relation between the optical density measured at 448 nm and the change in absorbed dose ($A=A_0-A_i$) where A_o and A_i are the values of the optical density at 448nm for the unirradiated and irradiated films. As shown in Fig. 3 increasing in intensity difference estimated values correlated with dye concentrations was noticed reflecting the effect of dye concentrations on the response curve that leads to extending the dose ranges accompanying each dye concentration.

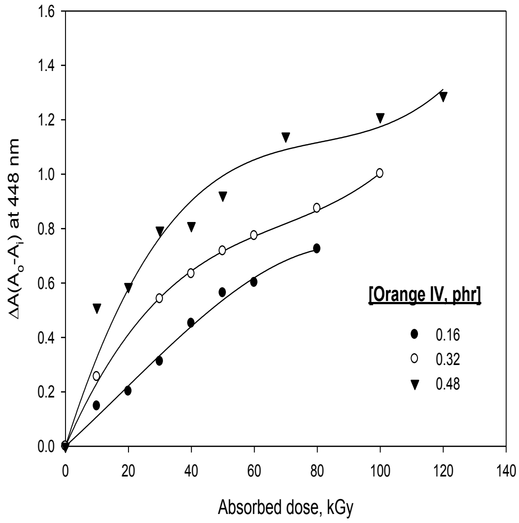


Fig. 3. Change of $\Delta A.mm^{-1}$ of Orange IV/PVA films containing different concentrations of dye [Chloral hydrate]= 8 phr at λmax= 448 nm

Effect of different concentrations of (CH) on the response curve

Figure 4 reveals the effect of the different chloral hydrate concentrations on the response curve through speedy reach to saturation target red color depending on chloral hydrate concentration added.

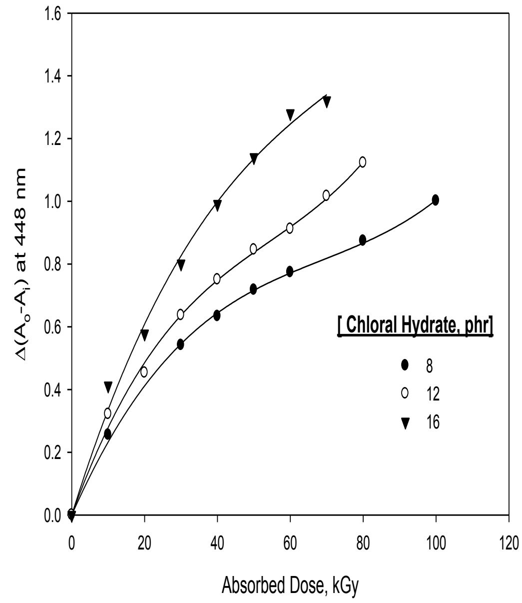


Fig. 4. Change of $\Delta A.mm^{-1}$ of Orange IV/PVA films containing different chloral hydrate concentrations [Orange IV]= 0.32 phr at λmax= 448 nm

Humidity during irradiation

The effect of relative humidity (RH) during irradiation on the response was investigated by irradiating orange1V/PVA films at (40 kGy) at different relative humidity ratios (0, 12, 33, 54, 76 and 92%). Irradiation was carried out while the films were suspended over various saturated-salt solutions in an closed jar, except for the 0% RH that was suspended over dried silica gel. Figure 5 shows the variation in response (ΔA) as a function of percentage RH during irradiation relative to that at 33%. The film has a good stability in relative humidity ranging from (10-50%). Attention should be paid to any other relative humidity and correction should be executed for accuracy point of view.

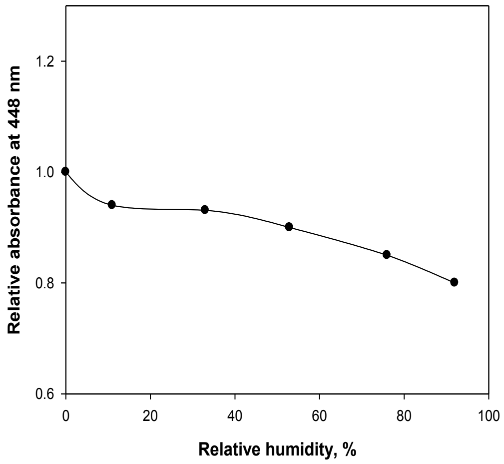


Fig. 5. Variation of the response of orange1V/PVA films as a function of relative humidity during irradiation at 40 kGy [Orange1V] = 0.32 phr

Pre- irradiation stability

The color stability of Orange IV/PVA film was investigated before irradiation by storing the film at 35% RH at room temperature under diurnal cycles of daylight. Figure 6 shows the change in relative absorbance of the tested film. It can be observed that the film exhibits an excellent stability before irradiation, where the variation in the absorbance during the 60 days storage period is 4 % and 1.8% at light and dark respectively.

Post irradiation stability

The post-irradiation stability of Orange 1V/PVA films [chloral hydrate= 8 phr] irradiated to 40 kGy was investigated by storing them in the diurnal cycles of daylight at room temperature. The absorbance of these films was measured at 448 nm at different intervals of time during the post-irradiation storage period of 60 days, as shown in Fig. 7. The Figure shows an excellent stability with a significant decrease at the end of the 60 days period of time estimated by 3% and 5% at dark and light respectively.

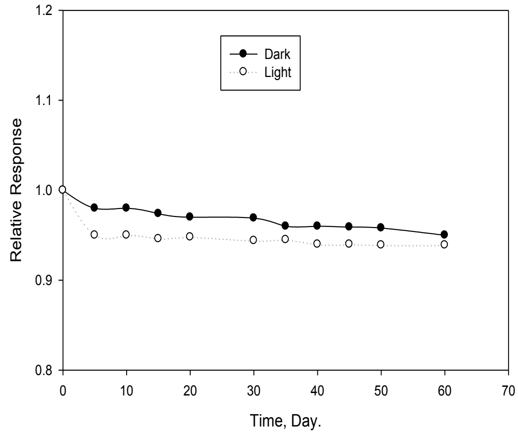


Fig. 6. Pre-irradiation stability of Orange IV/PVA films in terms of relative change in absorbance as a function of storage time

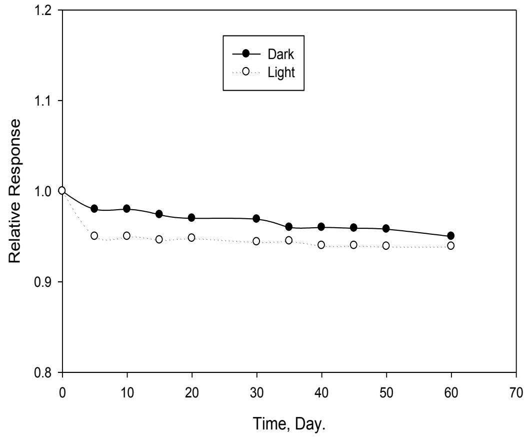


Fig. 7. Post-irradiation stability of Orange IV/PVA films in terms of relative change in absorbance as a function of storage time

Conclusion

The study focuses on the irradiation of Orange 1V /PVA films containing chloral hydrate seeking the possibility of using them in high dose monitoring. Upon irradiation, there is a significant color change from yellow to red due to the effect of the resulting HCL liberated from the decomposition of chloral hydrate. The amount of acid formed due to irradiation depends on the values of absorbed doses and the concentrations of chloral hydrate.

The recorded average dose range reached about 100 kGy. The response of the films is dependent on both dye and chloral hydrate concentrations. The response of these films has negligible humidity effects in the intermediate range of relative humidity ranging from (10-50%), correction should be done if used in RH beyond the specified RH range in this research. The films have excellent stability pre and after irradiation. The obtained data allow these films to monitor and determine the absorbed doses in low and high doses.

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