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Spectrophotometric properties of Eosin gel and its possible use as radiation dosimeter

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ABSTRACT

In this study, the spectrophotometric response of Eosin – gelatin gel dosimeter irradiated with gamma rays was characterized. Preparation of Eosin – gelatin gel takes place in neutral medium to form a pink hydrogel which has a sharp absorbance peak at 522 nm that bleaches upon irradiation. The useful dose range was 0.5 - 3 kGy. The dose-response function, radiation sensitivity, and dependences of the response to environmental factors were studied.

Introduction

Dosimetry is the science of dose measurement. It has a great importance in the establishment of a new radiation process, validation of the procedure, dose mapping, and routine dose process control to realize a quality control and assurance [1]. Dosimeters of different nature have been studied to produce various dosimetric systems such as ionization chambers, diamond detectors, semiconductor detectors, ESR dosimeters, radiochromic films, thermo luminescent dosimeters (TLDs), infrared luminescence dosimetry [2]. Polymer gel dosimeters are a tissue equivalent material composed of chemicals which polymerize in an aqueous gelatin matrix as a function of the absorbed dose. Aqueous gels have been used with natural polymers such as gelatin or agarose forming the gel matrix [3] Polymer gel dosimeters are useful tool in radiotherapy [4-6]. Many techniques can be used to investigate the chemical changes in molecular structures. For example, NMR and FT-IR [7]. Several polymer gels have been developed, such as BANG (composed of bis-acrylamide, acrylamide, nitrogen, and gelatin). The Fricke Xylenol Gel (FXG) dosimeter is based on the Fe^{+2} to Fe^{+3} oxidation due to ionizing radiation, forming the [Fe^{+3}-OX] complex, whose absorbance peak is centered at 585 nm. Spectrophotometric measurements of the Fricke–gelatin–xylenol orange (FGX) gel dosimeter demonstrated reproducible linear dose response up to 25 Gy. Advanced work on Fricke gels with using water soluble, nontoxic and cheap polymer which is poly-vinyl alcohol (PVA) with high concentration of PVA (such as 20 % w/v) and other formulation of gels by adding glutaraldehyde (GTA) using a concentration of PVA in the gels of 10 % w/v [2].The new Fricke gelatin dosimeter with Methyl thymol blue (MTB) was replaced instead of XO in Fricke gel systems which has high sensitivity, and unaffected diffusion comparing with these XO-containing gels [8].Several attempts to discover new monomers with lower toxicity because the main source of toxicity in polymer gel dosimeter is its monomer [9]. New gel dosimeters are aqueous compositions containing 2,3,5triphenyltetrazolium chloride or 4,4-benzylidenebis (N,N-dimethylaniline) (leucomalachite green) and poly(ethylene oxide)-block-poly(propylene oxide)-block-poly(ethylene oxide) (Pluronic F-127), which form a physical gel matrix are prepared and using as Radiochromic gels for UV radiation measurements in 3D [10]. A novel polymer gel dosimeter based on itaconic acid are prepared and can be applied in the dose range 75 - 1000 Gy [11]. Prepared azo dye metal-complex; solution of 1,5 diphenyl carbazone (DPC) chelating with chromium(III) in gelatin used as colored gel dosimeter in dose range 0.02 - 1kGy [12]. A new dyed–gelatin gel of Fuchsine acid cyanide (FAC) dye in gelatin for low-dose dosimetry applications and the gel color change was measured at 550 nm using UV-vis spectroscopy technique, it can be used as a dosimeter in dose range 1 to 170 Gy [13]. Toluidine Blue O (TBO)-gelatin gel dosimeters are Prepared and the colour change

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can be measured with UV-VIS spectrophotometer. The useful dose range was 1 - 150 Gy [14]. Eosin/PVB films which prepared by casting method as film dosimeter, the radiation-induced bleaching of the Eosin color is faster by adding chloral hydrate to the films because the radiolysis products of chloral hydrate enhance the bleaching reactions of Eosin. Eosin/PVB films are useful as routine high-dose dosimeters in dose range 120 to 450 kGy [15].

The current work aimed to investigation of a new dosimetry system of Eosin dye as gel dosimetry system and studies the spectrophotometric response of Eosin – gelatin gel dosimeter irradiated with gamma rays. The dose response function, radiation sensitivity, and dependences of the response on environmental factors were studied. Advantages of Eosin – gelatin gel as gel dosimeter comparing to other Eosin dosimeter such as Eosin /PVB film dosimeter are reported.

Subjects and Methods

Preparation of Eosin - gelatin gel dosimeter

Stock solutions containing 0.08g of Eosin dye $C_{20}H_6Br_4Na_2O_5$ (product of Riedel De-Haen) were prepared by dissolving it in 100 mL distilled water stirred for 4 hours.Three different concentrations of dye (0.5, 1.1 and 1.5 mL) and gelatin (Product of El-Nasr Pharmaceutical Co. Egypt) concentration is 10 % w/w (that is, the mass of gelatin relative to the mass of the final gel). Gelatin was dissolved in distilled water and then the Eosin dye was added from a stock solution. The mixture was continuously stirred in a water bath. The solution forms a pink colour. Since the reaction rate is dependent on temperature, the water bath was maintained at 70 ± 5ºC for 4 h. This temperature was chosen for a fast colour change while keeping the temperature reasonably constant. Gel samples were pipetted into 1 cm thickness glass test tube and immediately placed in a refrigerator at approximately 4ºC for 4 h.

Apparatus

The absorption spectra of both unirradiated and irradiated dyed gel samples were recorded in the wavelength range of 200 - 800 nm using a UVIKON 860 spectrophotometer (Kontron Co. Ltd., Switzerland). Irradiation carried out with the ^{60}Co Gamma chamber 4000A irradiation facility (manufactured at Bhabha Atomic Research Centre, India). The absorbed dose rate in the irradiation facility was measured to be 6.25 kGyh-1.

Results and discussion

Absorption spectra

The absorption spectra of the unirradiated and irradiated shows absorption band in the visible region at 522 nm which is characteristic to a pink color for dyed polymer gel as shown in **Fig. 1**. It is shown that the amplitude of all absorption bands in the visible spectra decreases gradually with the increase of the dose of the gamma-ray photons in the dose range between 0.5 and 9 kGy.

Response curves

Group of gel samples were irradiated with dose rate of 6.25 kGyh^{-1} in the range between 0.5 and 9 kGy. The resulting gel color has an absorbance peak at 522 nm, this peak bleaches upon irradiation as the gel bleaches. **Fig. 2** shows dose response curves of the gel-dyed samples with various concentrations of Eosin. Each dose point corresponds to four replicated test tube samples. The dose dependences are linear up to 3 kGy. **Fig. 3** the linear correlation coefficients were found to be 0.2441, 0.2871 and 0.3793 for the prepared (dyed-gel) concentrations 0.0256, 0.0564 and 0.0769 mmolL^{-1}, respectively.

Radiation chemical yield (G-Value)

The molar extinction coefficient of Eosin had been found to be 22312.74 L.mol^{-1}.cm^{-1}. The radiation chemical yield was calculated from the linear portion of the response curve (*ΔA* vs. dose). The calculated G-value for these gels and the concentration of the dye inside the solution were tabulated in **Table 1**. From the table it could be noticed that the G-value increases with the increase of the dye concentration as shown in **Fig.4**. This may be due to the number of radiolysis products of polymer (as OH, H, OH^-, H^+,…..). This result reflects the important role of the formed free radicals in the bleaching process.

Reproducibility of gel samples

The evaluation of the overall coefficient of variation (CV %) for the spectrophotometric measurements of gel samples irradiated reported a good reproducibility in the dose range 0.5 - 3 kGy. Three replicate measurements were made at each absorbed dose value (n = 3). The overall coefficient of variation (CV %) at a confidence level of 95 % was calculated to be 4.1 % [16] using the equation:

$$CV\% = \sqrt{\frac{\sum_i (n_i - 1)(\sigma_{i-1} / \overline{X}_i)^2}{\sum_i (n_i - 1)}} \quad \textbf{X 100} \qquad (1)$$

where σ_{i-1} is the sample standard deviation for ith set of measurement, n_i-1 is the degrees of freedom for ith set of data, X_i the average value of spectrophotometrically for ith set of measurement, n_i the number of replicate measurements for ith set of data.

Radiation sensitivity

Radiation sensitivity is the susceptibility of a material to physical or chemical changes induced by radiation. Because the changes in samples are spectrophotometric properties changes, the sensitivity of the gel samples to radiation doses expressed as the slope of the dose-response curve, increases linearly with the dye concentration **Fig. 5.**

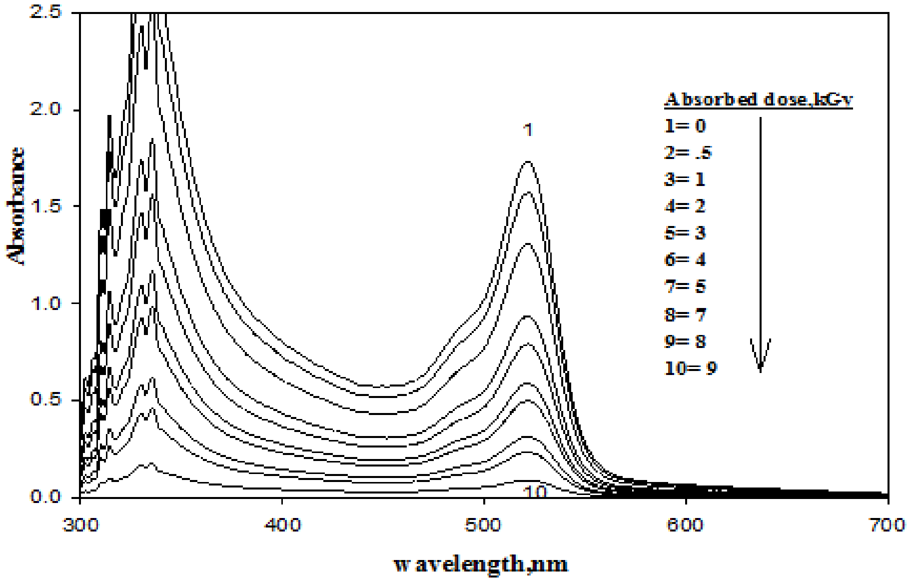

Fig. 1: The absorption spectra of unirradiated and gamma irradiated (Eosin – gelatin) gel to different absorbed doses [0.0769 mmolL^{-1}].

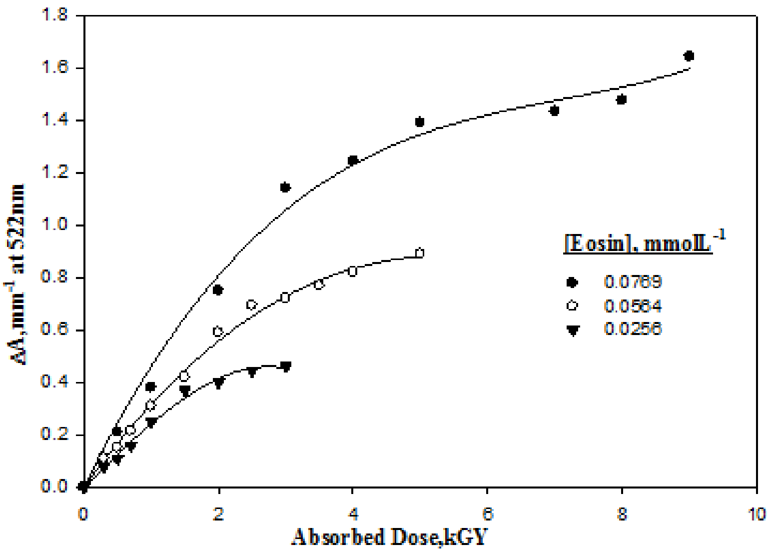

Fig. 2: Response curves of the (Eosin – gelatin) gel at 522 nm in the full dose range of 0.5 –9 KGy.

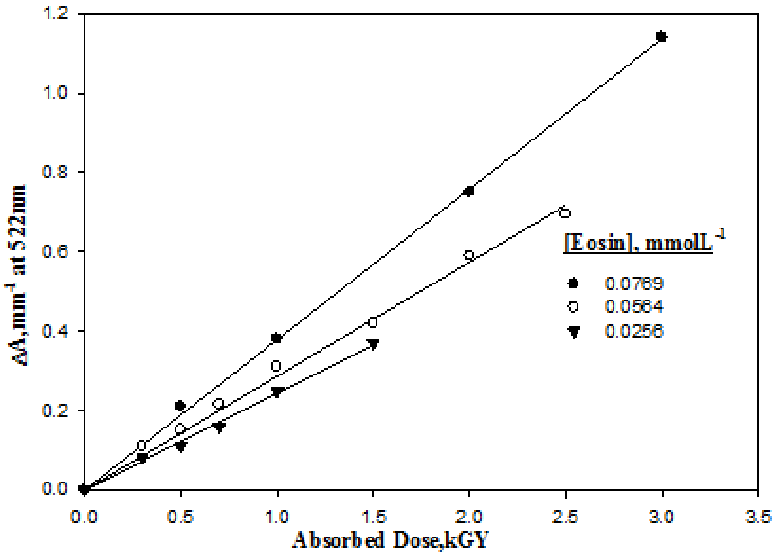

Fig. 3: Linear dose response of the (Eosin – gelatin) gel at 522 nm.

Table 1: The calculated G-values for (Eosin – gelatin) gel at different dye concentrations

[Eosin]. mmolL^{-1}	G-value, µmol/J
0.0256	0.008614
0.0564	0.010132
0.0769	0.01339

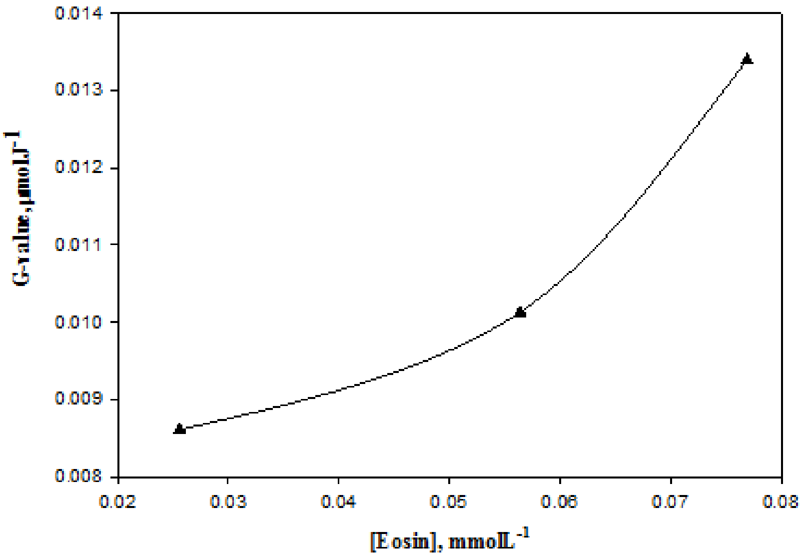

Fig.4: Change of G-values at 522 nm as a function of concentration of Eosin dye.

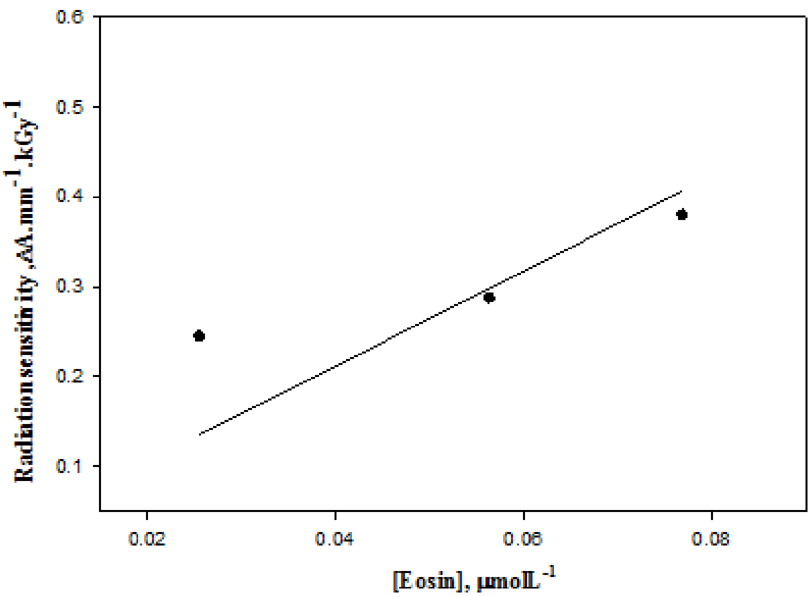

Fig.5: Change of radiation sensitivity at 522 nm of (Eosin - gelatin) gel as a function of concentration of Eosin dye.

Pre-irradiation stability

To investigate possible effects of pre-irradiation **s**torage on the prepared gel samples, we monitored the absorbances of unirradiated gel samples stored under different conditions. Two groups of gel samples prepared and their absorbencies at 522 nm was monitored for 36 days. One of the groups was stored at room temperature in the dark and another group was stored at room temperature exposed to laboratory fluorescent light at **Fig. 6**, the absorbencies of the samples stored in the dark at -4^{0}C remained essentially unchanged during the whole period of the observations. The absorbances of the samples stored at room temperature in the dark changed about 1 % over the same period of time. However, the absorbances of the gels stored at room temperature under fluorescent light increased by approximately 3 % by the end of the observation. So; storage of unirradiated gels in the dark at -4^{0}C is recommended.

Post -irradiation stability

(Eosin – gelatin) gels were irradiated to 1kGy. After the irradiation, they were stored under different conditions. One group was stored at room temperature under laboratory fluorescence light and another group was stored at -4^{o}C in the dark. The absorbances of the samples at 522 nm were measured periodically over 36 days of storage **Fig. 7**. The absorbance of the samples stored at -4^{0}C was very stable over the whole observation period. On the contrary, the responses of the samples stored at room temperature under laboratory fluorescence light, increased rapidly during the first week of storage and then grew more slowly until the end of the observation period.

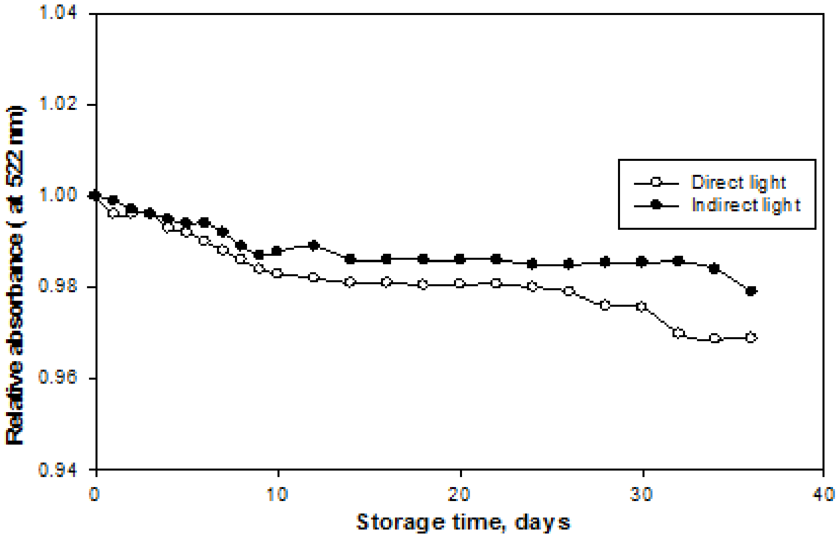

Fig. 6: Pre -irradiation stability of (Eosin – gelatin) gels stored under different storage.

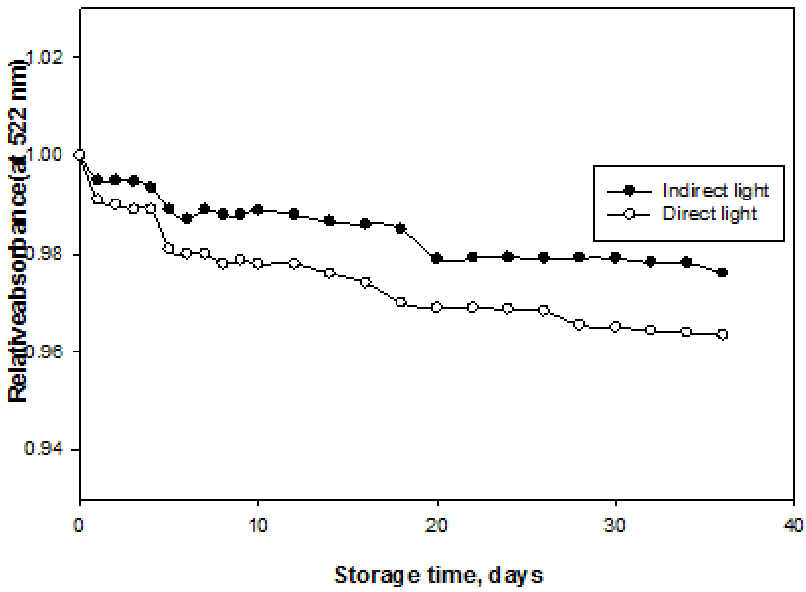

Fig.7: Post -irradiation stability of (Eosin – gelatin) gels stored under different storage conditions (irradiated at 1kGy).

Applications

The effect of gamma ray on different concentrations of prepared Eosin – gelatin gel was investigated. Upon gamma radiation, the color of the prepared gel (red color) bleached with the increase of absorbed dose. Moreover, it can be applied in the dose range of 0.5 to 3kGy that make it applied in food irradiation, medical sterilization, wastewater treatment, and food irradiation processing **Table 2**. On the other hand, the prepared gel dosimeter has a good stability before and after irradiation during two months at light and dark. Furthermore, the change in color in gel dosimeters was measured through UV-Vis Spectrophotometer. In conclusion, many advantages of these prepared dosimeters that is easy-operation, cost-effectiveness, high selectivity and sensitivity, and applicable for many applications as mentioned above.

Table 2: Comparison between Eosin dyed poly (vinyl butyral) Films [15] and Eosin - gelatin gels

Dosimeter	Dosimetry system	Useful Dose range	λ_{max}, nm	applications
Eosin/PVB	Film dosimetry system	120-150 kGy	533 nm	- routine monitoring - dose mapping in radiation processing
Eosin -gelatin	Gel dosimetry system	0.5-3 kGy	522 nm	- food irradiation - medical sterilization - wastewater treatment

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