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Characteristics of a New Polymer Gel for Low-dose Dosimetry Applications

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THE EFFECT of gamma irradiation on absorption properties of carbolfuchsin (CF) with gelatin blended for possible use in dosimetry and measurement of radiation dose in gamma rays have been studied using UV-Visible spectrophotometer method. The gelatin (polymer gel capsulated dyed) were irradiated to different accumulated doses from 1 up to 50Gy using gamma rays source at a constant dose rate. The absorption spectra were measured using UV-Visible spectrophotometer in the wavelength range (200 to 900) nm, resulting in a decrease of the absorbance at 560nm band peak with increasing dose.

Keywords: Irradiation, Carbolfuchsin dye, Gel, Polymer, Dosimeter and gamma rays.

Dosimetry plays an important role in the quality control of radiation processing [(1)]. Gel dosimetry gains more acceptance in radiation oncology as a mean of measuring 3D dose distribution profiles, which provides quality assurance of radiation treatments. Hydrogels infused with a radiation-sensitive material have the ability to retain dosimetric information in 3D[(2)]. Modeling of the dosimeter's radiological properties demonstrates that this gel can be considered water equivalent (*i.e*. the chemical structure of gelatin shows that it is a poly peptide compound contained in many amino acids, which contains -NH-CO- in its structure. It can be easily croosslinked with the dye through a weak hydrogen bond –NH- as derivative for measuring 3D dose of kilo-voltage and megavoltage x-ray beams [(3)]. The induced color bleaching of organic dyes under gamma irradiation has been reported by some researchers [(1,4,5)]. The gel dosimetry is a highly promising dosimetry method, which is useful for absorbed dose verification in complex clinical situation (*e.g*. intensity-modulated radiotherapy - IMRT) using 3D geometry phantoms [(6)]. For routine dose monitoring in radiation processing, the polymeric dyed flexible films are considered the most common as dosimeters, dose labels and indicators [(6)].

Genipin, a fruit extracted from *Gardenia jasminoides* Ellis, is a cross-linker of proteins, such as gelatin, forming blue pigments [(7,8)]. As the genipin cross-links the gelatin, the solution slowly changes from colorless to blue and steadily darkens over time. This blue hydrogel is radiochromic[(9)].In general studies it's

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appear that when dyed plastic films exposed to irradiation, there are three possibilities occurred as follow: No response, bleaching or color changes [(10)].

Material and Methods

Gel preparation

The polymer gel samples and carbolfuchsin (CF Product of SIGMA, Chemical Formula [C17H19 N. HCl]) were prepared by using a solvent casting method. The gelatin powders (300 blooms, G2500, Sigma-Aldrich) was dissolved in distilled water at 70±5 °C in a water path and prepared stock solution from CF by dissolving 0.04g in 50 ml double distilled water, the solution was stirred for 24 hr. When cooled polymer gel at 30°C then added different concentrations from CF and the volatility until a homogeneous compound was obtained. Samples were pipetted into 1 cm thickness glass test tube and immediately placed in a refrigerator at approximately 4°C. (This method of preparation was followed as similar preparation method previously published in the present field of radiation dosimetry). This was concerned with characterization of tetrazolium violet-polyvinyl alcohol films, which obtained a colored film after irradiation diffus the dye into the pores of the polymer[(11)]. Similarity, in this case we dissolve the polymer gel "gelatin" in distilled water and a stock solution of the dye diffused into the gelatin to form gel mixture content. However, the difference between the first method when film was applied in case of high dose applications up to 20 kGy, on the contrary, in present case the gel was applied in low dose range from 1-50 Gy.

Irradiation and measurement

The absorption spectra of un-irradiated and irradiated gel samples were measured throughout the wavelength range 200-900 nm using a UV-Visible spectrophotometer (Uv ikon 860 spectrophotometer (KONTRON Co. Ltd., Switzerland). Gamma irradiation was carried out in the ^{60}Co gamma chambers 4000A (product of India). After irradiation carried out, the gel sample measured spectrophotometrically not delayed than 2hr due to the higher sensitivity of the gel toward the surrounding environmental conditions. The absorbed dose rate in the irradiation facility was measured to be 1.37 kGy/hr. (we didn’t calculate the dose inside the gel, but we calculated the absorbed dose, obtained ready from the office of gamma irradiator facility responsible for dose mapping and dose rate calculations).

Result and discussion

Absorption spectra

In the current work, the absorption spectra of the polymer gel containing CF were recorded before and after irradiation to different absorbed doses. (The results obtained are in Fig.1). The absorption spectra of the un-trradiated and irradiated polymer gel in the wavelength range 200-900nm shows, one peak in the visible region at 560nm, which is characterized by pink color. Upon irradiation, the peak at 560 nm is gradually decreases; *i.e.* bleaches, relative to amount of absorbed dose but the peak remain at the same position. When rose-colored polymer gel containing CF was irradiated with gamma rays, the hydrogen radicals liberated from polymer reduce the dye molecule leading to bleaching.

These polymer gel can expose to γ-rays at different doses (0-50 Gy accumulated dose as mentioned before) with constant filed of exposure, distance from the source, at room temperature and dose rate.

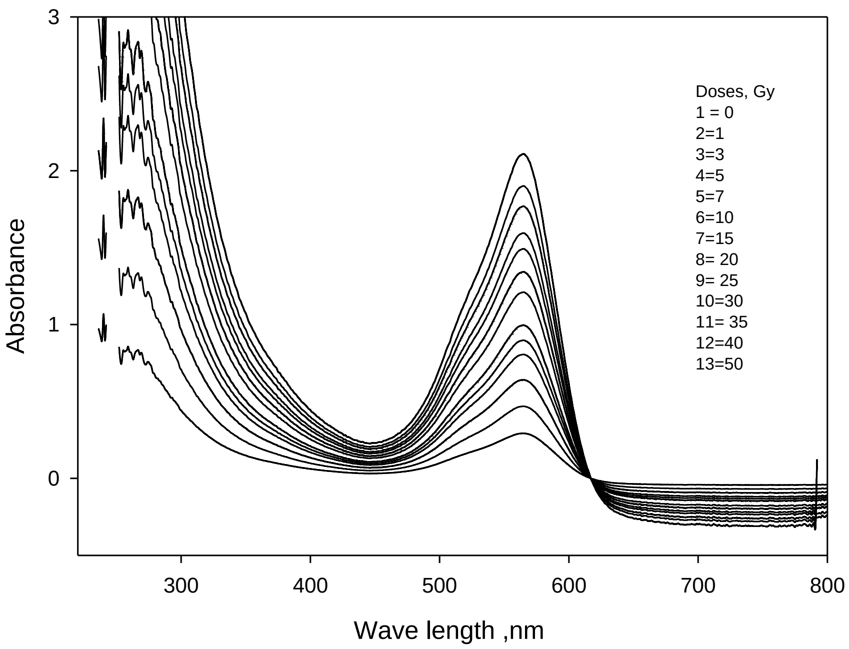

Fig. 1. The absorption spectra of dyed polymer gel (CF + Gel) un-irradiated and irradiated to different absorbed doses.

Dose response

The dose response functions in terms of net absorbance change, ($\Delta A = A_0 - A_i$), as a function of absorbed dose, where A_o and A_i are the absorbance's at 560 nm of the unirradiated and irradiated (polymer gel +CF) are shown in Fig. 2. From this figure, it can be seen that the figure is linear for all the dose range, so this dose range can choose to be a useful dose range for this dosimeter.

The dose response functions of the polymer gel with various concentrations of CF. Each dose point correspond to four replicate samples. The dose dependences are linear up to 10Gy (Fig. 3). The linear correlation coefficients were found to be 0.997,0.998, 0.996 and 0.995 for the gel with the CF concentrations of 5,10, and 15 phr, respectively.

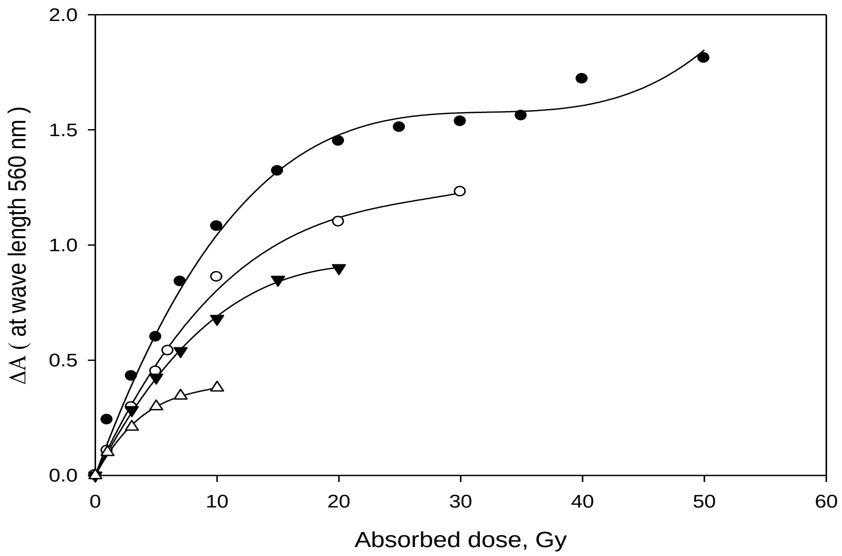

Fig. 2. Change of absorbance at 560 nm as a function of absorbed dose of dyed polymer gel (CF + Gel).

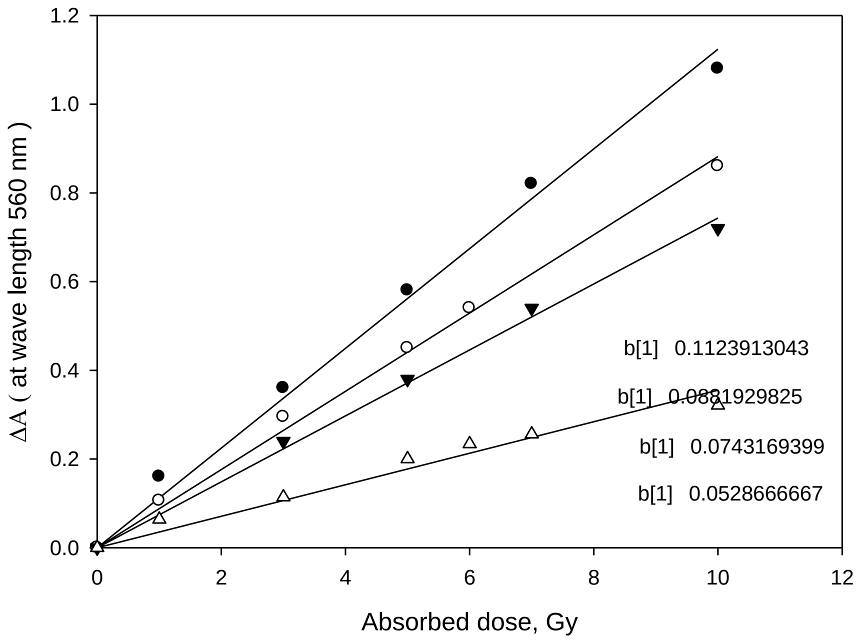

Fig. 3. Linear change of absorbance at 635 nm as a function of absorbed dose dyed polymer gel (CF + Gel) .

Dose sensitivity

The sensitivity of the polymer gel to radiation doses, expressed as the slope of the dose response curve, increases linearly with the CF concentration (Fig. 4). The polymer gel with 15 phr of CF is about 2.5 times more sensitive than the polymer gel with 5 phr of CF. The effect of CF concentration on the dose sensitivity was shown in Fig. 5.Whilst the maximum sensitivity for CF concentration is 2.5 ml and greater, these results indicate a trend towards improved stability for low CF concentration. A high concentration of gelatin has a detrimental effect on the dose response sensitivity.

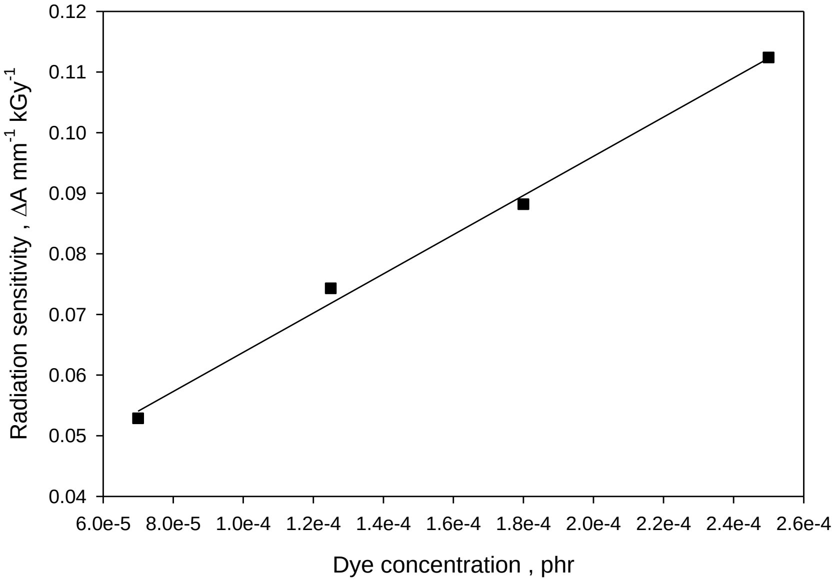

Fig. 4. Change of Radiation sensitivity at 635 nm as a function of concentration of dyed polymer gel (CF + Gel).

Radiation chemical yield (G-Value)

The radiation chemical yield can be expressed as the number of moles of the dye degraded by absorption of 1 J of energy. The *G*-value was calculated using the general relation**:**

G-(value) = $\Delta A / D\varepsilon\rho b$ (mol/J),

where ΔA is the change in absorbance at λmax, ***b*** is the optical path length (1 cm), ε is the linear molar extinction coefficient for the solution at λ_{max} ($L.mol^{-1}.cm^{-1}$), it calculated from the slope obtained from plotting relation between the dye concentrations in Mol/L against absorbencies of these concentrations, this linear relation plotted and the slope of this relation is the molar extinction coefficient. ***P*** is the density of the polymer gel ($g.cm^{-3}$), and ***D*** is the absorbed dose (Gy). The molar extinction coefficient of CF had been found to be 1.760049×10^5 $L.mol^{-1}.cm^{-1}$. The radiation chemical yield was calculated from the linear portion of the response curve (*ΔA*vs. dose). Figure 4 shows the calculated *G*-values for various dye concentrations.

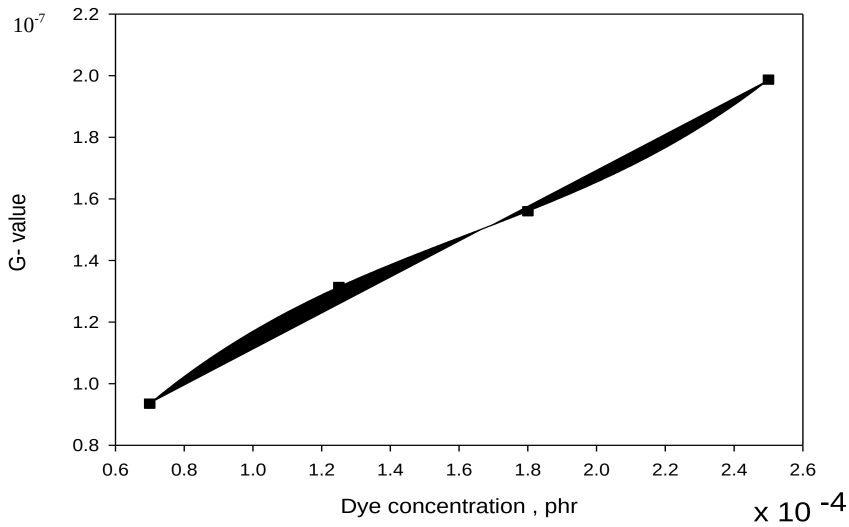

Fig. 5. Change of G-values at 635 nm as a function of concentration of dyed polymer gel (CF + Gel).

Pre and post-irradiation stability

Pre and post-irradiation stability (shelf life) measurements before irradiation of the dyed polymer gel were made by storing dyed polymer gel in light at ambient temperature. In addition, reading the dyed polymer gel UV-V is spectrophotometer at different times during the pre-irradiation storage period of more than 36 days shown in Fig. 6, 7. In contrast, dyed polymer gel stored in light showed dramatic decrease in absorbance.

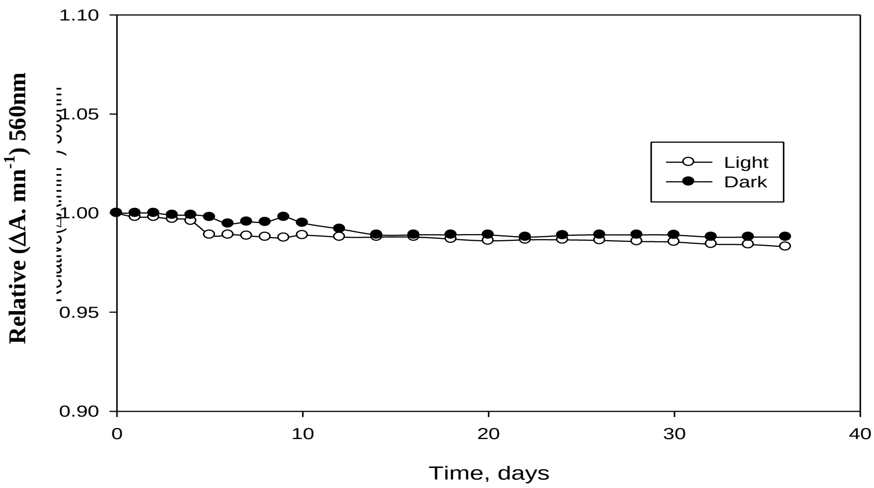

Fig.6. Pre -irradiation stability of (CF– polymer) gels stored under different storage conditions.

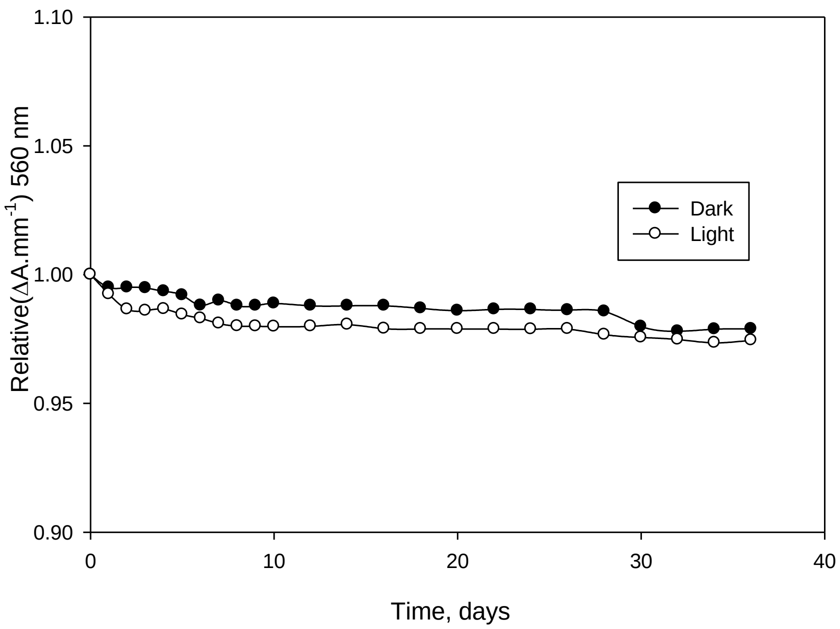

Fig.7. Post -irradiation stability of (CF – polymer) gels stored under different storage conditions

Conclusion

In this study, radiation-sensitive polymer gel containing carbolfuchsin dyes after irradiation with gamma rays can be used as a possible 3D dosimeter. The polymer gel had highly accurate radiation sensitivity in the 0–50 Gy dose range dosimetry. When this dyed gel exposed to accumulated doses from (0 to 50 Gy) in wavelength range (200 to 900) showed an absorption band at 560 nm. The fitting of the dose-response curves y=ax+b resulted in a linear relationship between dose and net absorbance change. The gel might have a high sensitivity to dose but might be inaccurate due to external conditions (light, temperature, humidity) and also processing method. Moreover, this type of dosimeter has an advantage as its stability extended to a month over than Frick xylenoyl orange which its stability do not exceed 7 days and the other type of gel dosimeter as acrylamide and bis acrylamide dosimeter which stability extended to 2 days only. The present gel shows higher sensitivity and was produced easily at lower cost; we expect that its use will lead to improved 3D dosimetry in low dose dosimetry applications as blood irradiation and radiotherapy dosimetry and gene-therapy. The prepared gel samples show an excellent stability before and after irradiation.

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خصائص بوليمر جل جديد لتطبيقات قياسات الجرعات الاشعاعية المنخفضة

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هذه الدراسة تتناول تحضير بوليمر جيل يستخدم في مجال الإشعاع مقياسا للجرعات الإشعاعية المنخفضة، وتم العمل على تطوير حساسية المدى الاشعاعى للأفلام المستخدمة فى البحث لتصل إلى ٥٠ جرام بحيث تفقد المواد المحضر منها البوليمر جيل لونها الوردي تدريجيا عند تعرضها للجرعات الإشعاعية فى المدى من ١-٥٠ جراى باستخدام أشعة جاما ، وقد تم قياس هذا التغير فى اللون باستخدام جهاز الطيف الضوئي وكما تم أيضا تقدير الناتج الكيميائي الاشعاعى بعد عملية التشعيع .

يتميز هذا الجيل المحضر فى هذا البحث عن غيره من المواد بان له درجة ثبات عاليه تتجاوز شهر من تاريخ تحضيره وقد تم دراسة تأثير الرطوبة النسبية أثناء عملية التشعيع بالإضافة إلى ظروف التخزين للأفلام قبل وبعد التشعيع لدراسة تغيير حساسية المواد عند التعرض لإشعاع جاما.