

Comparison between New (Gel/Liquid) Dosimeter for Radiation Dosimetry Applications

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Abstract— In this study, the effect of gamma irradiation on absorption properties of solochrome (SK) with polymer gel for possible use in dosimetry and measurement of gamma rays radiation dose has been studied using UV-Visible spectrophotometer method. In this paper, if come to compare between two dosimetry systems; we will sat that the first depends on the dye incorporating as gel dosimeter; while the second system depends on the same dye SK with gelatin to form a liquid dosimeter, and it was investigated that it is more sensitive toward γ rays. This study shows the induced absorption bands in the same visible violet spectrum showing a bleaching in the visible absorption spectrum. The dyed dosimeter gel/liquid was irradiated to different accumulated doses. The useful dose ranges from 0.01 to 1.5 kGy and from 1 to 9 kGy respectively, using gamma ray 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 535 nm and 562 nm band peak (in gel and liquid samples respectively) with increasing dose. The radiation sensitivity of two dosimetry System 3-D has been studied, as a function of concentration of the dye, pre/post-irradiation stability was studied.

Index Terms— Irradiation, absorption properties of solochrome (SK), absorption bands/ spectra, alkali blue dye, Gel, Polymer, Dosimeter and gamma rays.

1 INTRODUCTION

Dosimetry systems developed in standards laboratories utilise calorimetry, ionization and chemical methods for determining absorbed dose to water [1]. One chemical method, the gel dosimeter, in which substances carrying dosimetric information are suspended in a gel matrix, allows dose distributions to be measured in three dimensions (3D), promising true 3D quality assurance measurements in radiotherapy treatment planning. Readout techniques that have been developed include magnetic resonance imaging (MRI), optical computed tomography (CT), x-ray CT, ultrasound, and vibrational spectroscopy, offering significant advantages in obtaining dose distributions in gel dosimeters [2].

Gel dosimetry is gaining more acceptances in radiation oncology as a means of assuring the quality of radiation treatments. Genipin-gelatin gel shows promise as a stable, three-dimensional dosimeter for use in quality assurance for radiotherapy treatments. Genipin creates cross-links in gelatin, forming a blue colour that bleaches quantitatively upon irradiation. A formulation suitable for dosimetry was investigated by varying the concentrations of genipin, gelatin and sulphuric acid and determining the dose sensitivity [3].

Modeling of the dosimeter's radiological properties demonstrates that this gel can be considered water equivalent for depth dose measurements of kilo voltage and megavoltage x-ray beams [4]. The gel dosimeter, in which substances carrying dosimetric information are suspended in a gel matrix, can be used in quality assurance measurements in radiotherapy treatment planning [5]. The Fricke gel is widely used in some dosimeter system. Several basic experimental studies were performed on Fricke gels investigating the effect of the gelling substances [6], [7] and with chelating agents such as Xylenol orange to reduce diffusion in the dosimeter gels [8], [9]. In the other hand, Decoloration and degradation of a direct dye in

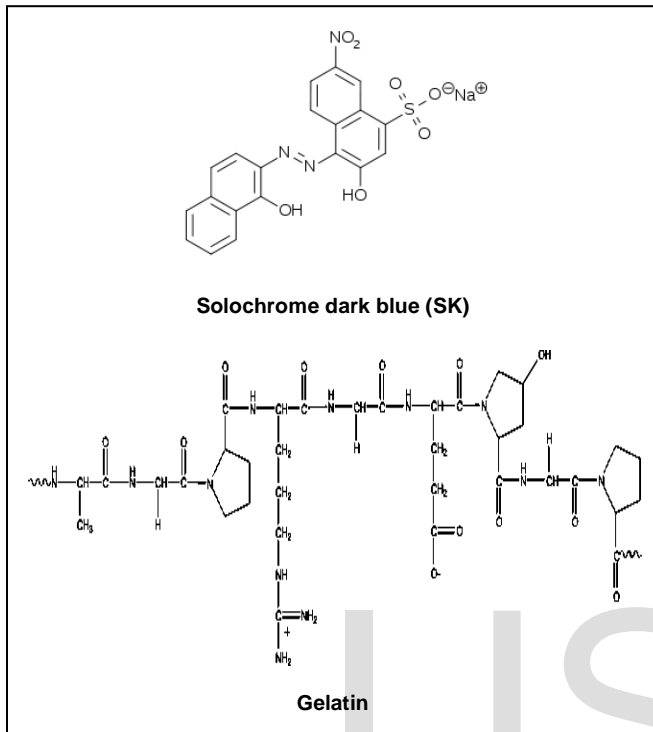
aqueous solutions by electron beam irradiation was studied. Some authors have proposed to use solutions of certain dyes in organic solvents as dosimetric systems and it has been shown that relatively low doses (below 10 Gy) may be measured using colour bleaching [10], [11], [12], [13], [14]. Electron beam irradiation can effectively decompose dye molecules, but higher absorbed dose is necessary to completely degrade the dye molecules to inorganic forms. As the concentrations of substrate increases, the decoloration and COD removal reduces. Increasing absorbed dose will increase decoloration percentage and COD [15]. The effect of radiation on a given compound depends on the composition of matter and the amount of energy that is transferred by the radiation. The radiolysis of water is very well documented and it been has known that it produces H₂, H₂O₂, H⁺, OH⁻ and hydrated electron, hydroxyl radical (\bullet OH) and hydrogen atom (\bullet H) as intermediate species in varying amounts depending upon the linear energy transfer value of the radiation [16]. Using g-rays or accelerated electrons, it is a simple and efficient technique. From economic point of view, combination of radiation and conventional methods, such as biological treatment is the most promising [17].

2 EXPERIMENTAL WORK

2.1. Materials

In this work, the polymer gel samples and SK (CF Product of Merck, Germany, M.F. C₂₀H₁₂N₃O₇SNa, M.wt 461.381 g/mol) were prepared by using a solvent casting method. The gelatin powders (300 blooms, G2500, Sigma-Aldrich) was dissolved in distilled water at 70±5 0C in a water path and prepared stock solution from SK by dissolving 0.04 g in 50 ml double distilled water, the solution was

stirred for 24 h. When cooled polymer gel at 30°C then added different concentrations from SK and the volatility until a homogeneous. Samples were pipette into 1 cm thickness glass test tube and immediately placed in a refrigerator at approximately 4°C.



the un-irradiated and irradiated both samples gel and liquid respectively).

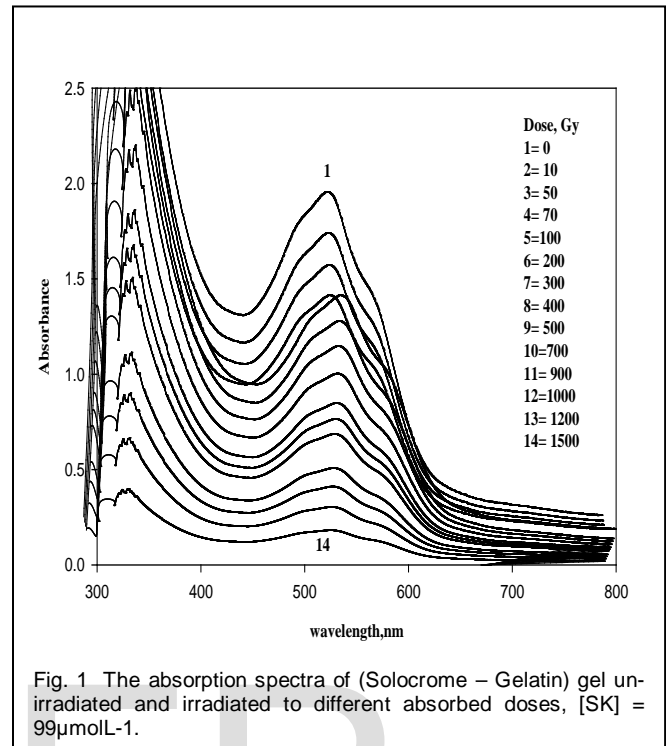


Fig. 1 The absorption spectra of (Solochrome – Gelatin) gel un-irradiated and irradiated to different absorbed doses, [SK] = 99 μ molL⁻¹.

2.2. Apparatus

γ irradiations were carried out with a Gamma chamber 4000A ⁶⁰Co irradiation facility (BARC, India). The absorbed dose rate in the irradiation facility was measured to be 1.37kGyh⁻¹. Uvikon 860 spectrophotometer (KONTRON Co. Ltd., Switzerland) was used to measure the absorption spectra of the un-irradiated and irradiated samples.

3 RESULTS AND DISCUSSION

3.1. Absorption spectra

The absorption spectra of the un-irradiated and irradiated shows absorption band in the visible region peaking at 535 nm (characteristic to a violet color) for dyed polymer gel Fig. 1 for different concentrations 23, 46, 77 and 92 μ molL⁻¹ of SK dye and peaking at 562 nm for dyed liquid, Fig. 2 for different concentrations; 19.25, 38.5, 57.8 and 77 μ molL⁻¹ SK dye as liquid dosimetry system. It is shown that the amplitude of all absorption bands in the visible spectra decrease gradually with increase of the dose of gamma-ray photons. It shows the response curves in terms of change of absorbance in terms of change in absorbance ($\Delta A = A_0 - A_i$, when A_0 and A_i are values of absorbance for

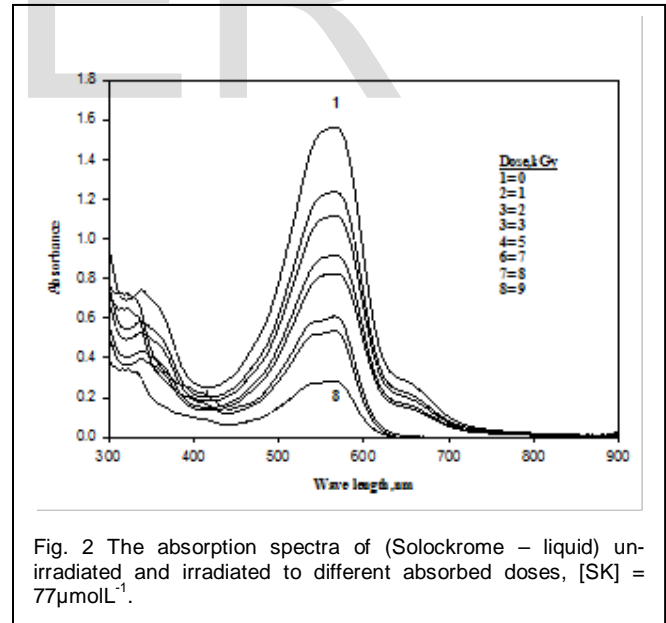


Fig. 2 The absorption spectra of (Solochrome – liquid) un-irradiated and irradiated to different absorbed doses, [SK] = 77 μ molL⁻¹.

3.2. Dose response

By comparing the results in this study were irradiated at each dose at room temperature, in air atmosphere and at dose rate of 1.37 kGy/h in the range between 0.01 and 1.5 kGy in the case of gel and the relative absorbance at 535 nm in fig.(1). However, In case of liquid dosimeter in

the range between 1 and 9 kGy and the relative absorbance at 562 nm in fig.(2). The resulting gel/liquid color has an absorbance peak at 535 nm and 562 nm, this peak bleaches upon irradiation. Fig. 3, 4 shows dose response functions of the gel/liquid dyed samples with various concentrations of Solochrome. Each dose point corresponds to four replicate test tube samples. The dose dependences are linear up to 100 Gy dyed gel Fig.4 and up to 1.2 kGy in Fig.6 this linearity that allows the stability of the gel/liquid response to be quantified.

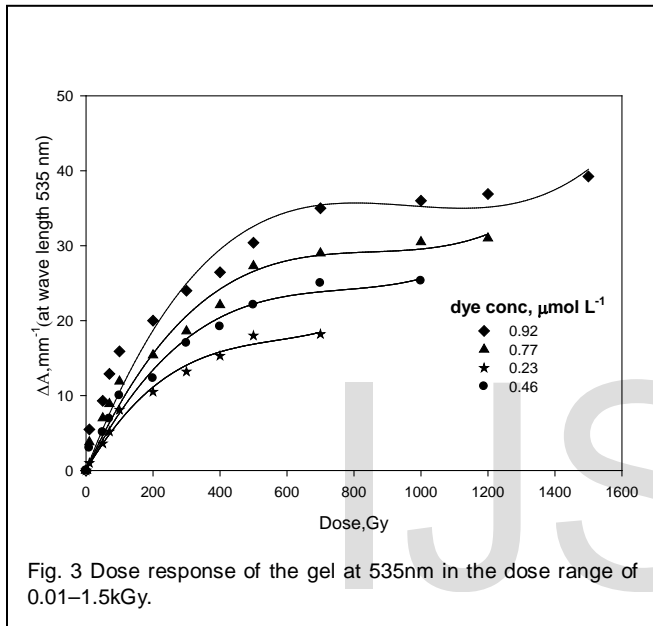


Fig. 3 Dose response of the gel at 535nm in the dose range of 0.01–1.5kGy.

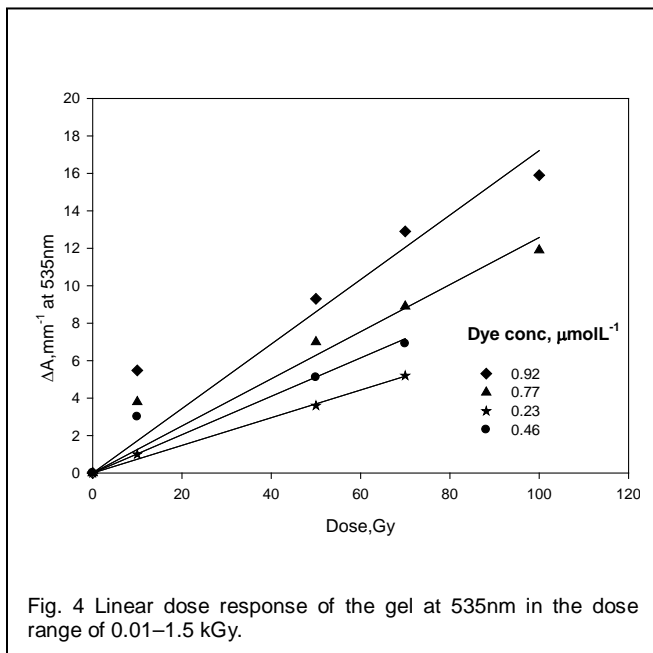


Fig. 4 Linear dose response of the gel at 535nm in the dose range of 0.01–1.5 kGy.

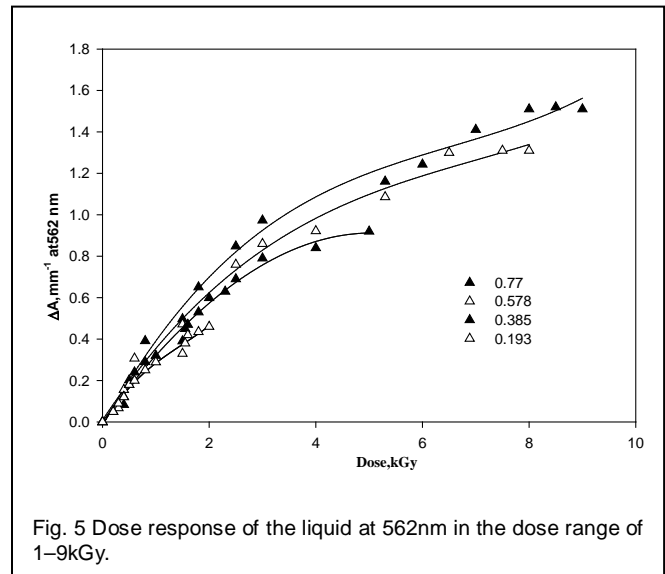


Fig. 5 Dose response of the liquid at 562nm in the dose range of 1–9kGy.

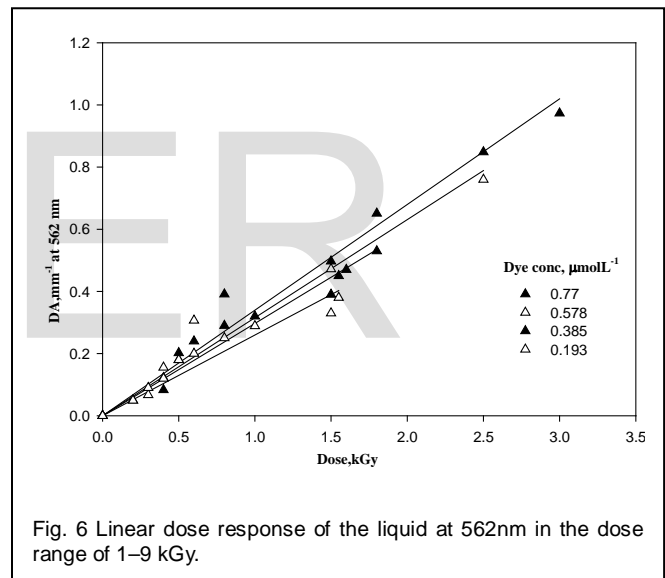


Fig. 6 Linear dose response of the liquid at 562nm in the dose range of 1–9 kGy.

Moreover, these results reflect the important role of gelatin in gel dosimetry system which increase the gel sensitivity toward radiation, this is clear from the two dose ranges from gel and liquid dosimetry systems.

3. 3 Sensitivity

The sensitivity of the gel/liquid samples to radiation doses, expressed as the slope of the dose response curve ($\text{cm}^{-1} \text{Gy}^{-1}$), increases linearly with the dye concentration Fig. 7, 8. Every experiment assessed the sensitivity and stability with the aim to determine the optimal dosimeter composition. A linear behavior was obtained in all cases; it may be observed that an increase in the dye concentration caused an increase in the response sensitivity.

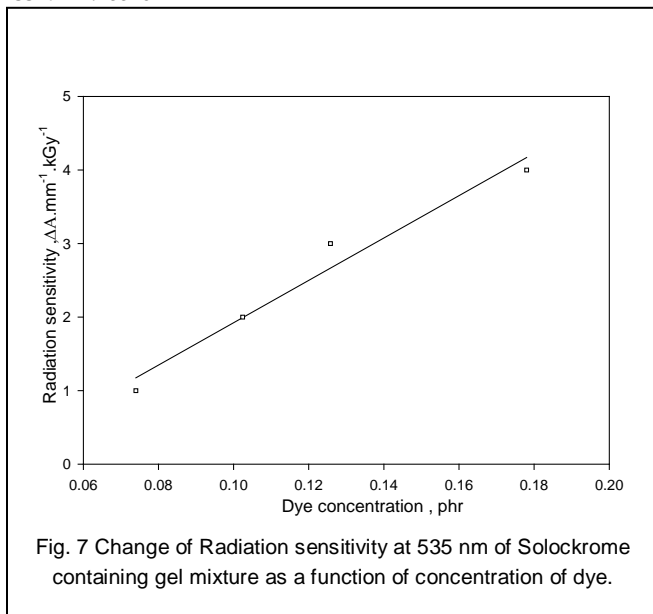


Fig. 7 Change of Radiation sensitivity at 535 nm of Solockrome containing gel mixture as a function of concentration of dye.

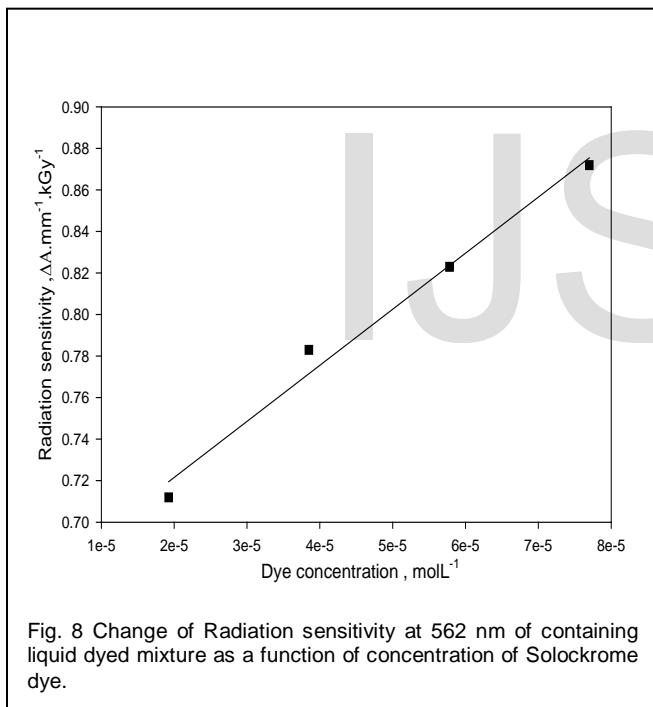


Fig. 8 Change of Radiation sensitivity at 562 nm of containing liquid dyed mixture as a function of concentration of Solockrome dye.

3. 4 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:

$$G = \Delta A / D \epsilon \rho b \text{ (mol/J)},$$

where ΔA is the change in absorbance at λ_{max} , b is the optical path length (1 cm), ϵ is the linear molar extinction coefficient for the solution at λ_{max} ($\text{L} \cdot \text{mol}^{-1} \cdot \text{cm}^{-1}$), ρ is the density of the polymer gel/liquid ($\text{g} \cdot \text{cm}^{-3}$), and D is the absorbed dose (Gy). The molar extinction coefficient of

Solockrome had been found to be 21791.5 and 25136.26 $\text{L} \cdot \text{mol}^{-1} \cdot \text{cm}^{-1}$ (for gel and liquid samples respectively). The radiation chemical yield was calculated from the linear portion of the response curve (ΔA vs. dose). Fig. 9, 10 show the calculated G-values for various dye concentrations. It was found that, G-value increase with the increase of absorbed doses.

TABLE 1

THE CALCULATED G-VALUE FOR GEL/LIQUID WITH SOLOCKROME AT DIFFERENT DYE CONCENTRATIONS.

Gel		Liquid	
Dye Con. μmolL^{-1}	G-value (gel) $\mu\text{mol/J}$	Dye Con. μmolL^{-1}	G-value (liquid) $\mu\text{mol/J}$
0.23	3.4	0.1930	0.2800
0.46	4.7	0.385	0.312
0.77	5.8	0.578	0.33
0.92	7.9	0.77	0.35

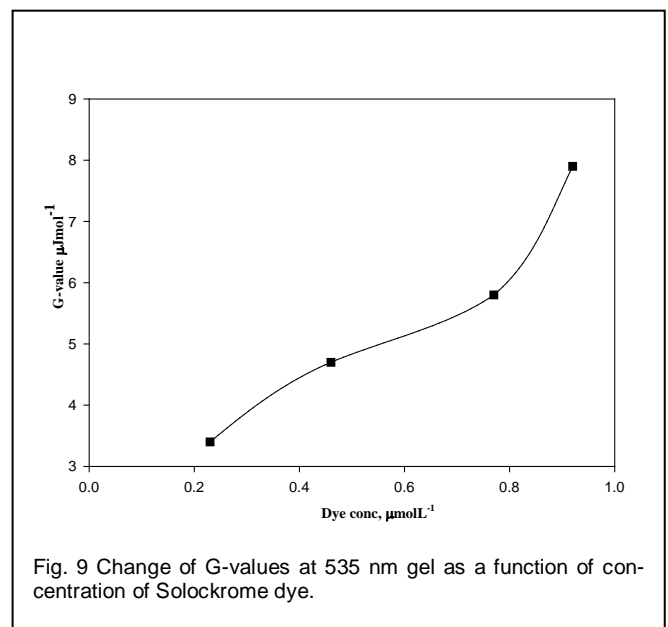
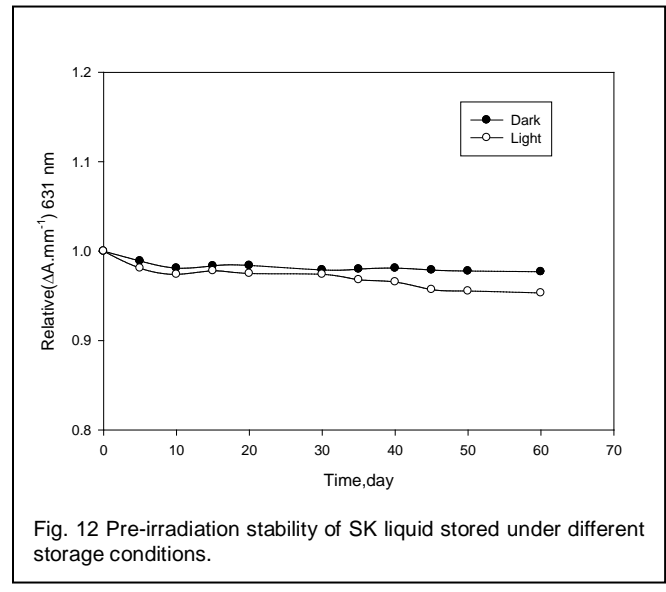
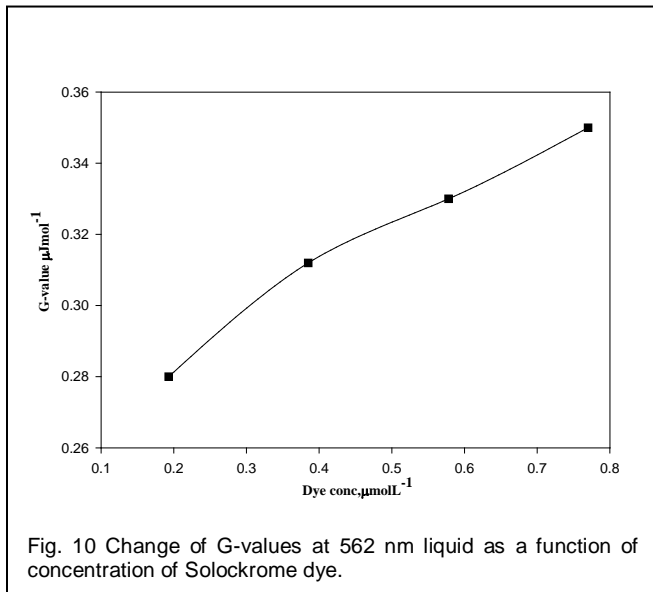


Fig. 9 Change of G-values at 535 nm gel as a function of concentration of Solockrome dye.

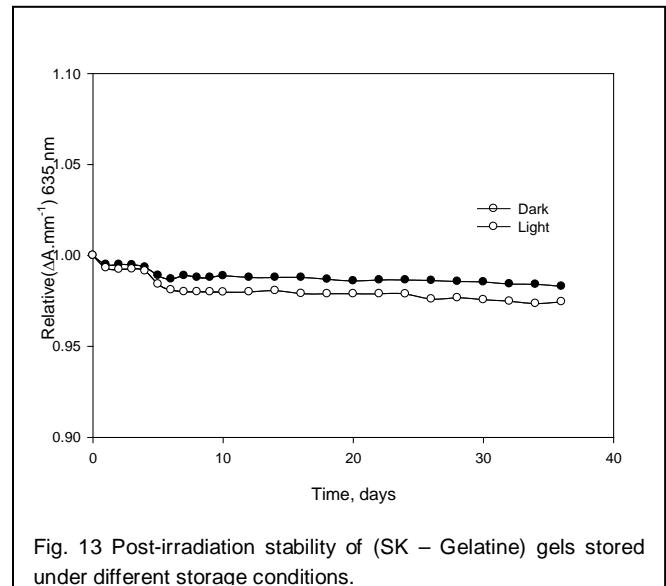
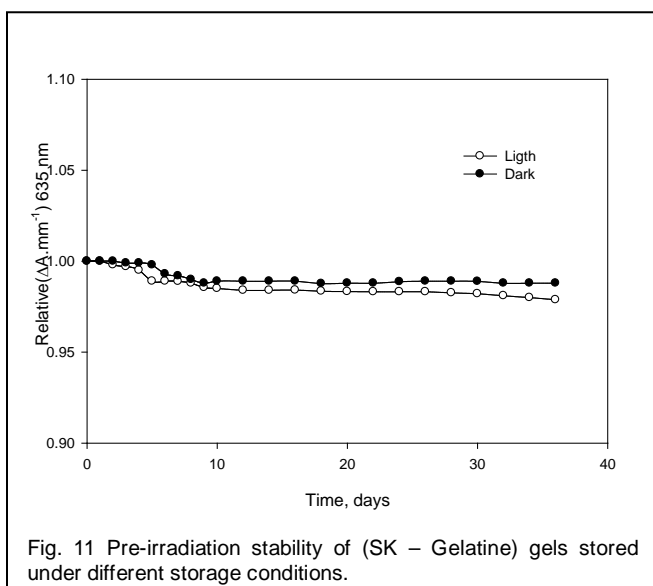


3. 5 Pre-irradiation Stability

The pre-irradiation stability of dyed gel/liquid irradiated to 1 kGy was investigated by measuring the absorbance of gel/liquid at 535 nm and 562 nm at different time and conditions. Two groups of gel/liquid samples manufactured approximately one month before the start of the experiment we restored under different conditions. One of the groups was stored at room temperature in the dark; another group was stored at room temperature exposed to laboratory fluorescent light Fig. (11, 12), the absorbances of the samples stored in the dark at -4 °C remained essentially unchanged during the whole period of the observations. In the case of gel is more stability than liquid dyed dosimeter.

3. 5 Post -irradiation Stability

In order to study the stability after irradiation, gel/liquid irradiated to 1 kGy were stored in dark and under laboratory fluorescent lights at room temperature (25 ± 3 °C). The variation of response as a function of storage time relative to that value measured immediately after irradiation is shown in Fig. (13, 14). The signals of the samples stored at -4 °C were 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.



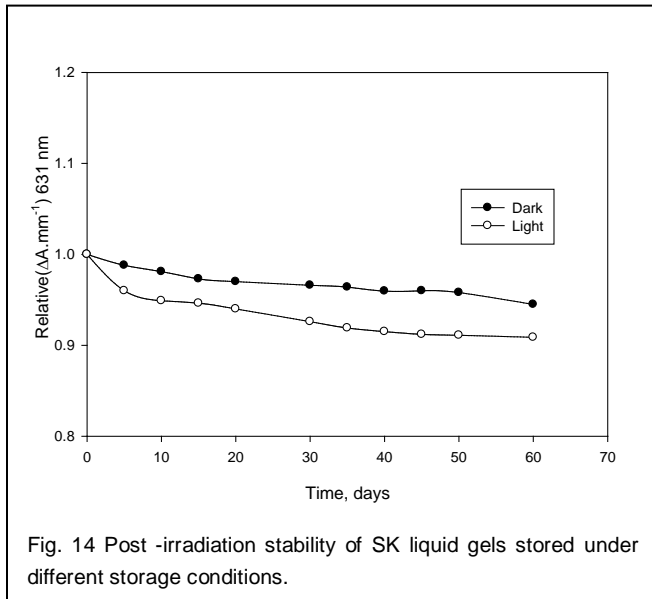


Fig. 14 Post -irradiation stability of SK liquid gels stored under different storage conditions.

4 CONCLUSION

Absorption spectra of gel/liquid peak at 535 nm and 562 nm respectively, which shifts towards the shorter wavelengths with increasing absorbed dose. The absorption measurements make it possible to determine radiation doses in the range from 0.01 to 1.5 kGy and 1 to 9 kGy (respectively). The radiation chemical yield, G-value, has been calculated. This study revealed, the higher sensitivity of the gel dosimeter comparing to liquid dosimeter. In addition to, the difference in the dose range leads to different applications; i.e. in case of gel dosimetry, system the dosimeter will be applied in low-dose dosimetry applications, but in the other case the liquid dosimeter will be applied in high-dose dosimetry applications. Finally, these dosimeters show a good stability before and after irradiation, a liquid dosimeter has long time stability than gel dosimeter. This is simpler, faster and much more economical and practical than the expensive MRI based-system for three-dimensional dosimetry and more reproducible gels. The gel can be produced in various shapes for specific applications. This can be done with easy quality control and at low cost.

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