Radiolytic Reduction of Aqueous Solutions of a Commercial Reactive Dye in the Range 0-100KGY by CO^{60} Gamma Radiation Source

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Abstract: Gamma dosimetric behavior of the aqueous solutions of the Sandalfix Golden Yellow CRL (SGY-145) dye was studied. The sample solutions of two chemical natures i.e., Acidic and Alkaline; were irradiated by Co^{60} γ-sources in the range 0-100kGy. The "Control samples" were remained un-irradiated and also chemically neutral. The dosimetry was done in three phases i.e., Low, Intermediate and High, ranging from 100-1000Gy, 1-10kGy and 10-100kGy respectively. The found values of the "λ_{max}" and the molar extinction coefficient "ε" of the dye were 467 nm and 3.4×10^3 $mol^{-1}cm^{-1}$ respectively. The absorbance (A) of the aqueous solutions was studied at the absorption band maxima (λ_{max}). The behavior of "Alkaline and Acidic solutions" was checked with the help of curve fitting.

Keywords: Chemical dosimeters, Sandalfix Golden Yellow CRL dye, dosimetry, optical density (OD), radiolytic bleaching.

1. INTRODUCTION

Radiation chemistry deals with the amount of energy absorbed from the gamma radiation. A quantitative estimation of the absorbed energy is called dosimetry and the system employed to perform this task is known as dosimeter. Currently, the amount of energy absorbed in the system from the gamma radiations is an active research area in chemical dosimetry. The state of art dosimeters requires calibration for their use as chemical dosimeters and thus termed as secondary dosimeters [1].

Several dosimeters i.e., ionization chambers, thermo-luminescent detectors (TLDs), radiographic films, silicon diode dosimeter, alanine dosimeter, plastic scintillators, diamond dosimeter, gel dosimeter, Fricke dosimeter and so forth, have been investigated for the evaluation of ionizing photons. However, dye dosimeters are well documented and different researchers have used various colors such as congo red [1], brilliant green [2], anionictriphenyl- methane dye solutions [3], methylene blue [4], chlorantine fast green BLL [5] and methyl red [6] to make dye dosimeters. The exposure of gamma radiations on the aqueous solutions of dyes leads to radiolytic bleaching. This bleaching property of the chosen dye makes the aqueous solutions able to be used for dye-dosimetry, since the decomposition of the dye depends linearly upon the amount of dose absorbed [1, 7, 8].

In the present study, the gamma dosimetric behavior of SGY-145 in the range 0-100kGy has been investigated to check its behavior in Low, Intermediate and High dosimetric ranges respectively, to observe the change in its λ_{max} and absorbance (A) with respect to the absorbed doses of gamma radiation. Moreover, these three radiation phases helped us out to determine the phase in which SGY-145 shows the linear response to gamma radiation. The feasibility of SGY-145 for gamma dosimetry in the range 0-1kGy was investigated proving that the SGY-145 dye follows the Beer's law so it can be used for the routine dosimetry without any qualm [9].

2. MATERIALS & METHODS

SGY-145 (Color Index: 145A, MW=1070amu), is available with the *Sandal Dyestuff Industries,* Pvt. Ltd. Faisalabad (Pakistan). One gram of the dye weighted by electrical balance (Sartorius Ag Gottingen BL2105, Germany) and was dissolved in one liter demineralized water. The stock solution was set at pH 7.0 measured by pH-meter (Hanna 8417). Two concentrations of the dye solutions were prepared such as C_1=1070 μmol/L and C_2=535 μmol/L. The solutions of pH 1-6 (with an interval of 1) in the present study were termed as "Acidic Samples" and those of pH 8-14 (with an interval

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of 1) were termed as "Alkaline Samples", while solutions of pH 7, which were remained chemically neutral and un-irradiated, were termed as "Control samples". The sodium hydroxide (NaOH) and hydrochloric acid (HCl) were used to set the pH of the samples, respectively. The sample solutions were preserved at room temperature [9, 10]. The dye has absorption band maxima i.e., λ_{max}=467nm which was determined by UV-Visible spectrophotometer (Lambda 25 1.27, PerkinElmer, USA). The absorbance (A) of the samples was measured at the λ_{max}. The structure of the SGY-145 is shown in Figure **1**.

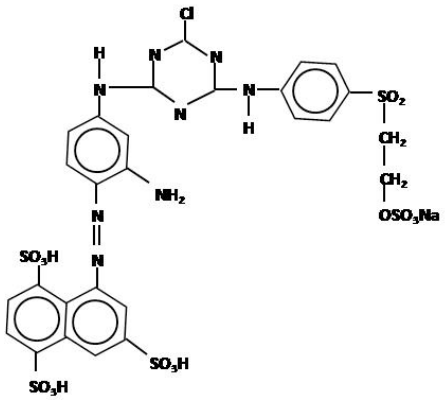

Figure 1: The structure diagram of the Sandalfix Golden Yellow CRL (C.I. 145A) dye.

2.1. Radiation Treatment of the Samples

The Co^{60} gamma radiation source from Pakistan Radiation Services (PARAS), Lahore (Pakistan), having dose rate 400Gy/hour was used for irradiation of the samples. Irradiation of solutions was carried out as follows: 5ml of solution was taken in a plastic vial of internal diameter 1.03cm and thickness 0.18cm with fit in plastic stoppers. The gamma radiation dose range was selected as 0-100kGy. Low, intermediate and high dosimetry were done by the γ-radiation doses in the range of 100-1000Gy (with a regular interval of 100Gy), 1-10kGy (with a regular interval of 1000Gy) and 10-100kGy (with a regular interval of 10,000Gy) respectively.

Table 1: Representation of the Parameters (Variables) of the Study

Variable	Representation
μ_1	Concentration (C_1)
μ_2	Concentration (C_2)
μ_3	Absorbance of Acidic samples (A_α)
μ_4	Absorbance of Alkaline samples (A_β)
μ_5	Absorbed dose (D)

Table 2: Matrix of the Correlation Coefficients Between the Parameters (Variables) of the Study

	μ_1	μ_2	μ_3	μ_4	μ_5
μ_1	1	0	1	1	0
μ_2	0	1	1	1	0
μ_3	1	1	1	0.9044	0.8709
μ_4	1	1	0.9044	1	0.8332
μ_5	0	0	0.8709	0.8332	1

3. RESULTS & DISCUSSION

In order to find the λ_{max} of the SGY-145 dye, the absorption spectra of the "Control and treated" samples were determined with the help of spectrophotometer (Lambda 25 1.27, PerkinElmer, USA) with reference beam cuvette containing the demineralized water. At this λ_{max}, absorbance of all the treated samples at each absorbed dose was measured.

Figure **2** shows the scan curves of the aqueous solutions of the SGY-145 dye treated in the range 0-1000Gy. It is clear from the figure that the primary absorption band maxima (λ_{max}) were 502nm.

Figure **3** shows the scan curves of the aqueous solutions of the SGY-145 dye treated in the range 1-10kGy. It is obvious from the figure that the primary absorption band maxima (λ_{max}) got two values in this range. The sample solutions treated at 1-5kGy showed the λ_{max} at 500nm and those of treated at 6-10kGy λ_{max} was at 445nm. This shift in λ_{max} of the dye was due to the breakage of Nitrogen double bonds (-N=N-) of the dye and after the degradation of the dye molecules, the pigments in the sample solutions were almost finished due to the bombardment of the gamma photons from the Co^{60} γ-radiation source [9, 11].

Figure **4** shows the scan curves of the aqueous solutions of the SGY-145 dye treated in the range 10-100kGy. The primary absorption band maxima (λ_{max}) of the samples radiated in high dosimetry has shifted from 500nm to the very low range of visible region, at 420nm, as the sample solutions were containing almost no dye molecules. This shift in λ_{max} of the dye was due to the breakage of Nitrogen double bonds (-N=N-) of the dye and after the degradation of the dye molecules, the pigments in the sample solutions were almost finished due to the bombardment of the gamma photons from the Co^{60} γ-radiation source [9, 11].

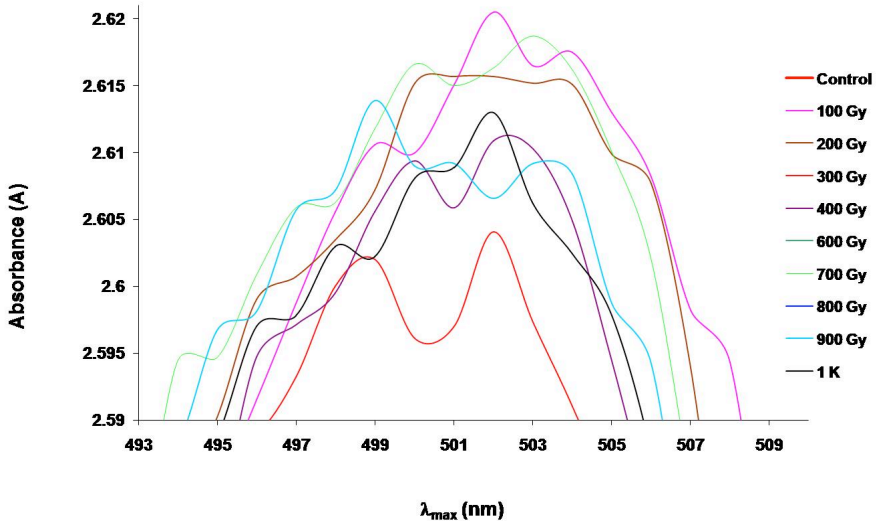

Figure 2: The determination of the absorption band maxima (λ_{max}) of Sandalfix Golden Yellow CRL within the dose range 0-1000Gy.

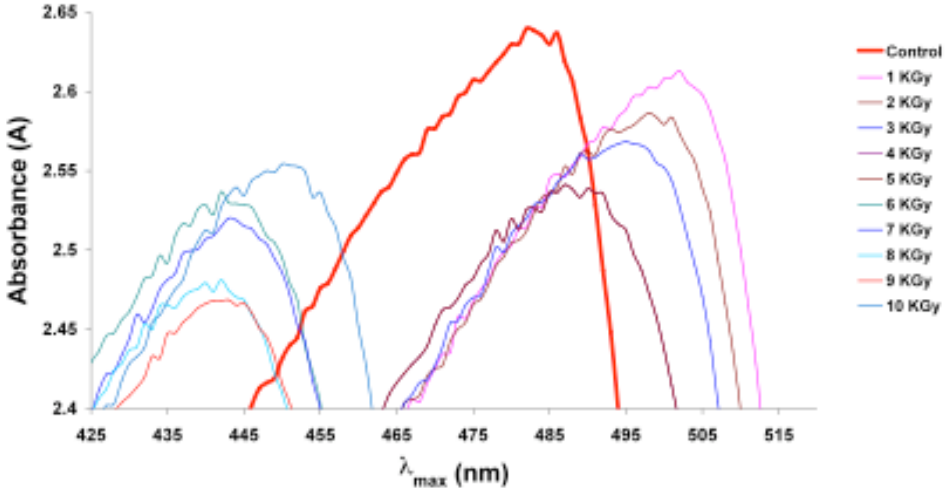

Figure 3: The determination of the absorption band maxima (λ_{max}) of Sandalfix Golden Yellow CRL within the dose range 1-10kGy.

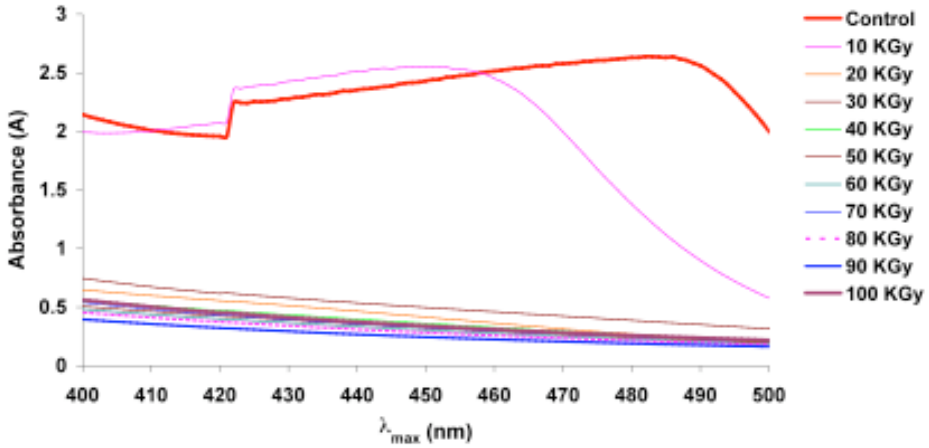

Figure 4: The determination of the absorption band maxima (λ_{max}) of Sandalfix Golden Yellow CRL within the dose range 10-100kGy.

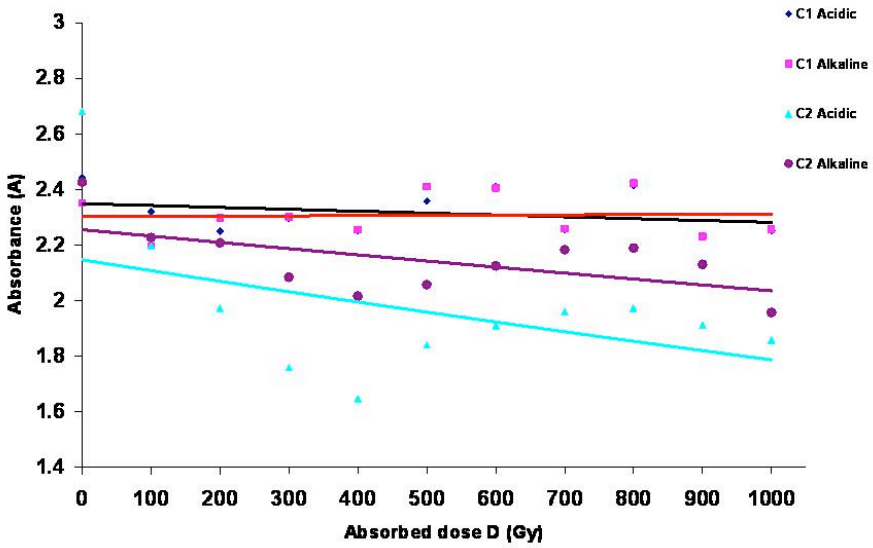

Figure 5: The decline in the Absorbance of Sandalfix Golden Yellow CRL in dose range 0-1kGy.

3.1. Low Dosimetry

The gamma radiation response for the aqueous solutions of the SGY-145 in terms of the absorbance (A) as a function of the absorbed dose (D) for low-dose dosimetry is shown in Figure **5**.

$A_{\alpha 1}$=2.35×exp(-0.00003D); R^2 = 0.0834 (3.1)

$A_{\alpha 2}$=2.15×exp(-0.0002D); R^2 = 0.2304 (3.2)

$A_{\beta 1}$=2.3×exp(0.000004D); R^2 = 0.0014 (3.3)

$A_{\beta 2}$=2.26×exp(-0.0001D); R^2 = 0.3514 (3.4)

Eq. 3.1-3.2 and Eq. 3.3-3.4 show the curve fitting for the "Acidic and Alkaline samples" of SGY-145 of concentration C_1 and C_2 respectively, treated at 0-1 kGy. Where "$A_{\alpha 1}$, $A_{\alpha 2}$" and "$A_{\beta 1}$, $A_{\beta 2}$" represent the Absorbance of "Acidic and Alkaline samples" of concentrations C_1 and C_2 respectively while D is the absorbed dose in Gy. Moreover, from equations (3.1-3.4) it is obvious that the samples of SGY-145 having concentrations C_1 and C_2 showed the exponential behavior of response with the absorbed dose range 0-1 kGy; range for "Low dose dosimetry".

3.2. Intermediate Dosimetry

The gamma radiation response for the aqueous solutions of the SGY-145 in terms of the absorbance (A) as a function of the absorbed dose (D) for Intermediate dosimetry is shown in Figure **6**.

$A_{\alpha 1}$=2.2×exp(0.00001D); R^2 = 0.6479 (3.5)

$A_{\alpha 2}$=1.34×exp(-0.00002D); R^2 = 0.0168 (3.6)

$A_{\beta 1}$=-0.00003×D+2.1894; R^2 = 0.6768 (3.7)

$A_{\beta 2}$=1.3×exp(-0.00002D); R^2 = 0.0324 (3.8)

Eq. 3.5-3.6 and Eq. 3.7-3.8 show the curve fitting for the "Acidic and Alkaline samples" of SGY-145 of concentration C_1 and C_2 respectively, treated at 1-10 kGy. Where "$A_{\alpha 1}$, $A_{\alpha 2}$" and "$A_{\beta 1}$, $A_{\beta 2}$" represent the Absorbance of "Acidic and Alkaline samples" of concentrations C_1 and C_2 respectively while D is the absorbed dose in Gy. Moreover, from equations (3.5, 3.6 and 3.8) it is obvious that the samples of SGY-145 having concentrations C_1 and C_2 showed the exponential behavior while equation 3.7 alone has shown anomalously linear response with the absorbed dose range 1-10 kGy; range for "intermediate dosimetry".

3.3. High Dosimetry

The gamma radiation response for the aqueous solutions of the SGY-145 in terms of the absorbance (A) as a function of the absorbed dose (D) for High dosimetry is shown in Figure **7**.

$A_{\alpha 1}$=2.5×exp(-0.000006D); R^2 = 0.9253 (3.9)

$A_{\alpha 2}$=1.2×exp(-0.00001D); R^2 = 0.3739 (3.10)

$A_{\beta 1}$=2.1×exp(-0.000007D); R^2 = 0.6482 (3.11)

$A_{\beta 2}$=1.03×exp(-0.00002D); R^2 = 0.8352 (3.12)

Eq. 3.9-3.10 and Eq. 3.11-3.12 show the curve fitting for the "Acidic and Alkaline samples" of SGY-145 of concentration C_1 and C_2 respectively, treated at 10-

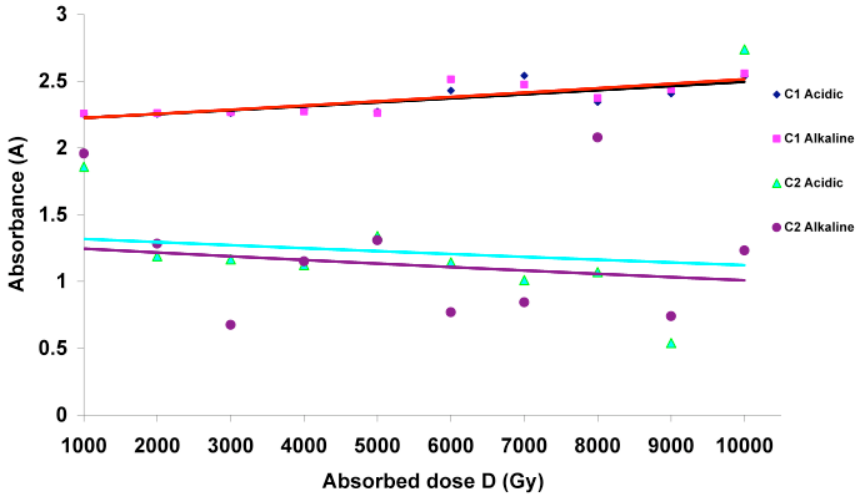

Figure 6: The decline in the Absorbance of Sandalfix Golden Yellow CRL in dose range 1-10kGy.

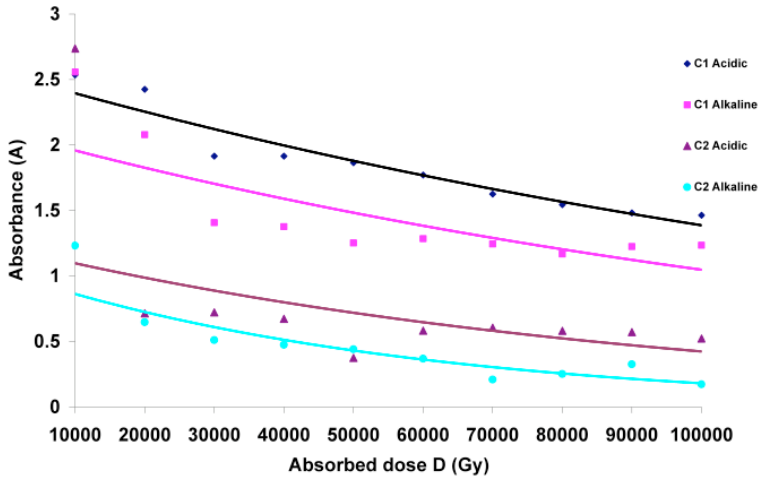

Figure. 7: The decline in the Absorbance of Sandalfix Golden Yellow CRL in dose range 10-100kGys.

100 kGy. Where "$A_{\alpha 1}$, $A_{\alpha 2}$" and "$A_{\beta 1}$, $A_{\beta 2}$" represent the Absorbance of "Acidic and Alkaline samples" of concentrations C_1 and C_2 respectively while D is the absorbed dose in Gy. Moreover, from equations (3.9-3.12) it is obvious that the samples of SGY-145 having concentrations C_1 and C_2 showed the exponential behavior of response with the absorbed dose range 10-100 kGy; range for "high dosimetry".

3.4. The Correlation Coefficients

Table **1** represents the parameters of the study whereas Table **2** shows the matrix of correlation coefficients among these parameters. The correlation coefficients of μ_1 and μ_2 have shown strong relationship with μ_3 and μ_4; whereas there is no relationship of μ_1 with either μ_2 or μ_5. Moreover, the correlation between μ_3 and μ_4 with μ_5 is also very appreciable showing the dependence of absorbance of Acidic and Alkaline samples on the absorbed dose (D).

3.5. Molar Extinction Coefficient

The molar extinction coefficient of the SGY-145 was found for both the concentrations i.e., C_1=1070 μmol/L and C_2=535 μmol /L and is shown in the Table **3**.

4. CONCLUSION

The aqueous solutions of the SGY-145 dye were found capable to be used as passive dosimeters in the range 1-10kGy i.e., they have shown very good response in the "Intermediate dosimetry" rather than "Low or High dosimetry". Table **3** depicts the molar

Table 3: Values of Molar Extinction Coefficient "ε" of SGY-145

Concentrations	Sample type	Molar Extinction Coefficient ε ($mol^{-1}cm^{-1}$)
Concentration (C_1)	Acidic samples (A_α)	0.2×10^4
	Alkaline samples (A_β)	0.19×10^4
Concentration (C_2)	Acidic samples (A_α)	0.49×10^4
	Alkaline samples (A_β)	0.48×10^4

extinction coefficient "ε" of SGY-145 dye for both concentrations has an average value of 3.4×10^3 $mol^{-1}cm^{-1}$ so it can be vividly stated that the pH of the sample solutions could not affect the response adequately. The astonishing behavior of this dye was its change in λ_{max} with respect to the absorbed dose. From 0-1kGy, the λ_{max} was on average 502 nm, however, it was found to decrease from 502 nm to 445 nm in the ranges 1-10kGy and finally in the high dosimetry, 10-100kGy, very low value of λ_{max} of the dye was found nearly at 420 nm within the visible region of the electromagnetic spectrum due to breakage of all the pigments of the dye molecules. The absorbance (A), being the dosimetric response of the dye, has shown exponential relationship with the absorbed dose (D) for both the concentrations C_1 and C_2 in the "Low, Intermediate and High dosimetry". The selected dye was found fit for "Low, Intermediate and High dosimetry". However, for future work, one may check the dosimetric response of this dye in some other solvents like Ethanol, Benzene etc. rather than the demineralized water.

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