Preliminary Studies for Dosimetric Response of a Synthetic Dye for Gamma Dosimetry

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Abstract: Aqueous solutions of Sandalfix Orange C2RL (SO) dye were used to check its feasibility as a new passive dosimeter. UV/VIS spectrophotometer was utilized to determine the absorption peak (λ_{max}) of dye; which was 430 nm. *SO* followed Beer's law satisfactorily. The absorbance (A) of the sample solutions was decreased with increase in absorbed dose (D). The %decoloration (%Đ) showed an exponential increase and logarithmic increase within low and high dosimetry range, respectively. The pH sensitivity of the sample solutions at different doses was also observed.

Keywords: Aqueous Solutions, Reactive Orange 122, Gamma radiation, %Decoloration, Absorbance.

INTRODUCTION

Biological, chemical and physical changes occur in material(s) exposed to radiations [1-2]. The process of calculating the quantity of absorbed Ionizing Radiations (IRs) is called *Radiation Dosimetry*. Some of the dosimeters are based on chemicals that respond linearly, logarithmically or exponentially etc. to IRs under suitable conditions. Chemical change upon irradiation is the general working principal of a chemical dosimeter. Irradiation can change the thermo-luminescence and other optical properties of alkaline earth and rare-earths metal compounds; which were conveniently used as a dosimeter.

Dye, a synthetic chemical; is used to impart color and has been used for dosimetric purposes in many of its forms like aqueous solutions [3-9] and polyvinyl alcoholic films [10-12] etc. In the aqueous solution, irradiation can cause the production of transient species i.e., ions and radicals etc. Radiolysis produces hydrated electron, H_2O_2, H_2, OH^-, H^+ and •OH radical as intermediate species; the production depends upon the linear energy transfer value of radiation [13]. Dyes are categorized on the bases of their source, color, structure and method of application in color index. Chromophoric groups are the major cause for the division of the dyes; and dyes can be characterized as azo dyes, arylmethane dyes, acridine dyes, nitro dyes, anthroqinone dyes, quinine-amine dyes and xanthene dyes [14].

Different dyes have been used by researchers i.e., bromophenol blue [15], methyl red [16], sandalfix golden yellow CRL and sandalfix red C4BLN [4-7], direct yellow 12 [13], methylene blue [10], alizarin yellow GG [17], reactive yellow 145 [18] and 2, 6 dinitro phenol [19] etc. Radiolysis causes degradation of the dye; and is a well-known radiation induced phenomenon. Degradation of the dye is initiated absolutely by •OH attacking on the electron-rich sites of the dye molecules and can be used for dosimetric studies.

The proposed plan of present study is to find the dosimetric response of aqueous solutions of the synthetic dye; when exposed to different gamma dose ranges.

MATERIALS AND METHODS

Sample Preparation and Pre-Irradiation Treatments

Sandalfix Orange C2RL (SO) (MW: 1034.27 amu, Molecular Formula: $C_{31}H_{20}ClN_7Na_4O_{16}S_5$) was collected from *Sandal Dyestuff Industries Pvt. Ltd. Faisalabad, Pakistan* and was used without further purification. The sample solutions were prepared by dissolving 0.5 gram (weighted by Mettler H35AR (USA) balance) of the selected dye in one liter of deionized water, collected from *Pakistan scientific traders, Faisalabad, Pakistan*, and it has electrical conductivity less than 1 μSiemens/cm. The pH of sample solutions was measured by pH meter (Hanna HI 83141) and controlled by using one molar solution of NaOH and HCl, respectively. The set of *acidic* samples have pH

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values 4, 5 and 6. The samples having pH 7 were kept chemically neutral and un-irradiated. The prepared solutions were stored in a black box to prevent the unwanted absorbance of light form the surrounding at ambient temperature. A double beam UV-Visible spectrophotometer (*Lambda 25 1.27, PerkinElmer, USA*) was used for the estimation of absorption band maxima (λ_{max}); absorbance (A) of all the solutions was measured at this λ_{max}. Cuvettes having path length of 10 mm were used to keep the sample solutions in the object beam.

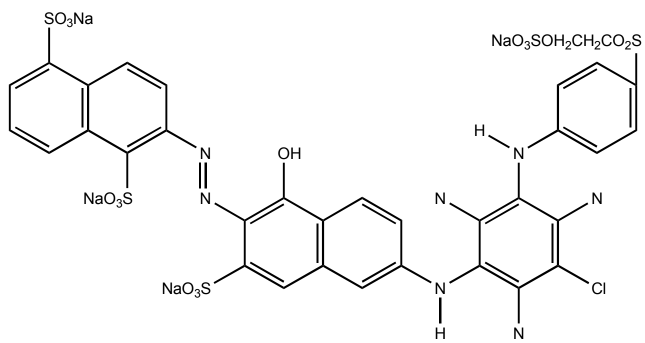

Figure 1: Schematic diagram of SO.

The N=N group was responsible for the color of the dye and found to be radiation sensitive as decoloration of the dye solutions was observed when exposed to gamma radiation flux [20].

Post-Irradiation Treatments

Cs^{137} γ-source (having dose rate 660Gy/h) from *Nuclear Institute of Agriculture and Biology (NIAB), Faisalabad, Pakistan,* was used for irradiation purposes. A stand was used to hold the samples at a fix position in the radiation source. The irradiation of sample solutions was carried out as follows: 5ml of solution was taken in a glass ampoule of internal diameter 1.03 cm and thickness 0.18 cm with fit in ground stopper. The sample filled ampoules were placed in the γ-ray field at a fixed position; and exposed for predetermined interval of time. The irradiation process was categorized in two phases; 0.1-1 kGy and 10-100 kGy i.e., *low* and *high* dosimetry, respectively, and stored in dark for the determination of the irradiation induced effects in the dye solutions.

RESULTS AND DISCUSSION

Response Curves

Response curves were examined for concentration (C) versus absorbance (A), %decoloration (%Đ) against absorbed dose (D), absorbance (A) versus absorbed dose (D) and absorbance (A) against pH of the sample solutions.

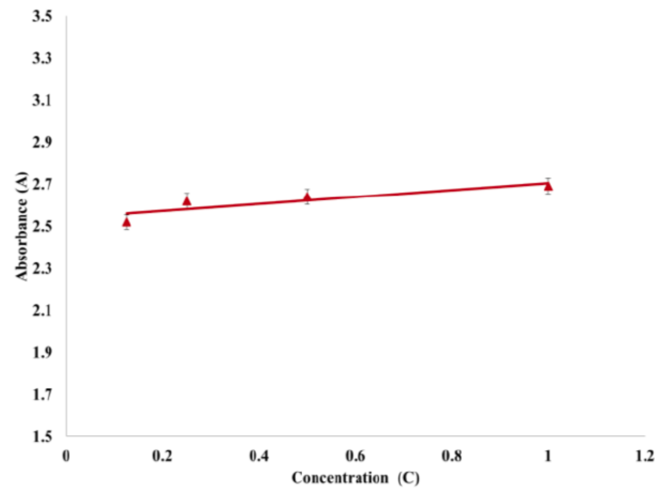

Figure 2: The effect of concentration on the absorbance (A) of sample solutions of SO.

Figure **2**, represents the behavior of Absorbance with respect to Concentration of the sample solutions of *SO* and hence they follow Beer's law satisfactorily and the mathematical equation for this behavior is given by:

$$A_{\circ} = 0.16 \times C + 2.5; \qquad R^2 = 0.8 \qquad (T)$$

Where, $A_{\circ}$ is the absorbance of the acidic samples having different concentrations (C) of the selected dye. Equation (*T*) represents the curve fitted for absorbance (A) and concentration (C), along with the strong correlation coefficient (R^2) among them.

The decoloration (Đ) is caused by the radiolysis of aqueous solutions; an evidence of structural damages due to gamma irradiation. The %decoloration (%Đ) can be calculated in terms of absorbance (A) of the samples at pre and post irradiation stages as given in equation 1 [17].

$$\%Đ = [(A_{\circ} - A_i)/ A_{\circ}] \times 100 \qquad (1)$$

Where, "%Đ" is the percentage decoloration, $A_{\circ}$ is the mean absorbance of the pre-irradiated *acidic* samples and "A_i" is the mean absorbance of the post-irradiated samples.

$$\%Đ = 1.75 \times e^{0.003D}; \qquad R^2 = 0.8 \qquad (2)$$

$$\%Đ = 12.06 \times \ln(D) - 49.15; \qquad R^2 = 0.8 \qquad (3)$$

The %decoloration (%Đ) was found to be increased exponentially as absorbed dose (D) increased from 100 to 1000 Gy. Logarithmic increase in *%Đ* was observed

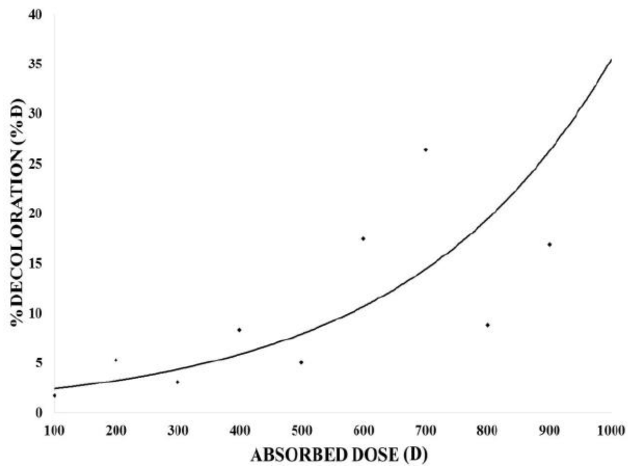

Figure 3: The exponential increase in %decoloration (%Đ) with respect to absorbed dose (D) for low dosimetry.

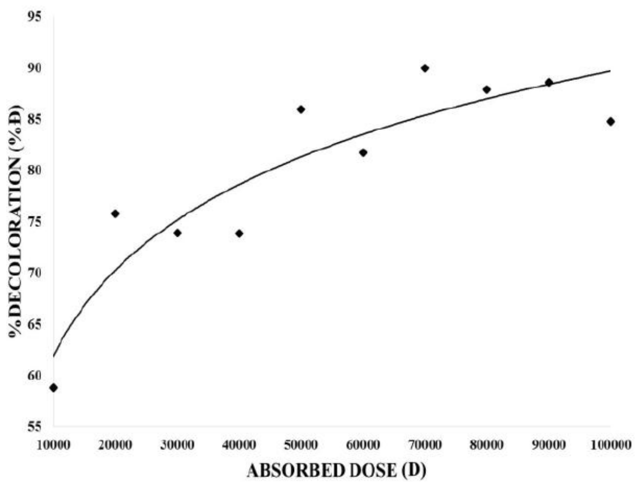

Figure 4: The logarithmic increase in %decoloration (%Đ) with respect to absorbed dose (D) for high dosimetry.

for high dose dosimetry. Equations 2 and 3 are the regression models for *low* and *high* dosimetry along with correlation coefficients, respectively; showing the strong relationship between the *%Đ* and absorbed dose (D).

$$A_4 = -0.001 \times (D) + 2.72; \qquad R^2 = 0.4 \qquad (4)$$

$$A_5 = -0.0008 \times (D) + 2.83; \qquad R^2 = 0.5 \qquad (5)$$

$$A_6 = -0.0011 \times (D) + 2.95; \qquad R^2 = 0.5 \qquad (6)$$

Where, A_4, A_5 and A_6 represent the absorbance (A) of the samples having pH 4, 5 and 6, respectively. Equations 4-6 represent the regression models and the values of correlation coefficients (R^2) of the linear behavior of dosimetric response of *SO* with respect to absorbed dose (D). The response of the *acidic* solutions in low dosimetry range showed a linear decrease in absorbance (A) with increase in absorbed dose (D).

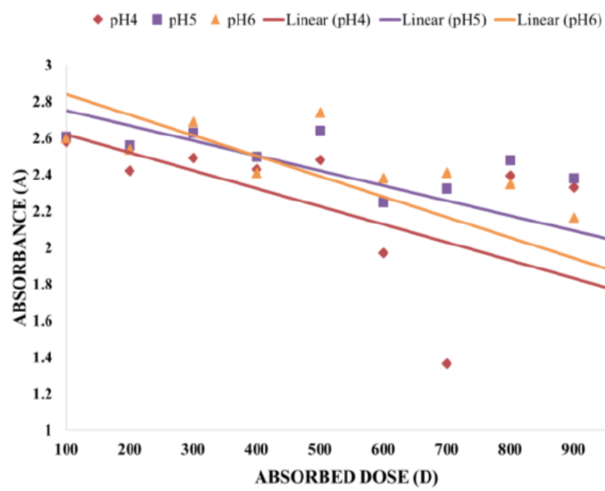

Figure 5: Response curve of Absorbance (A) versus Dose (D) for low dosimetry.

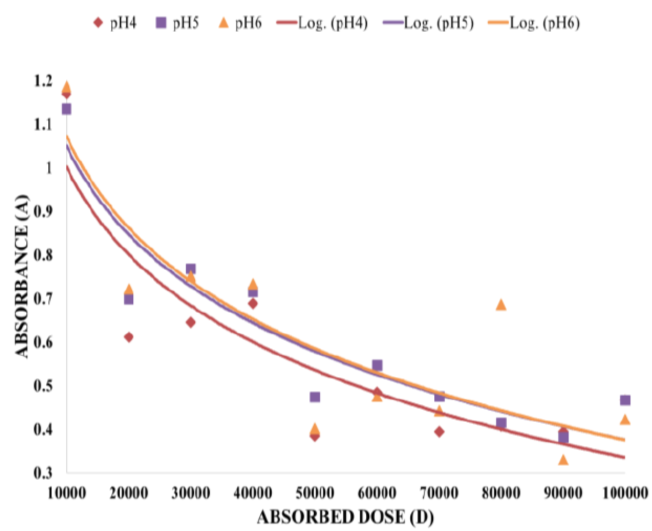

Figure 6: Response curve of absorbance (A) vs absorbed dose (D) for high dosimetry.

$$A_4 = -0.29 \times \ln(D) + 3.67; \qquad R^2 = 0.8 \qquad (7)$$

$$A_5 = -0.29 \times \ln(D) + 3.75; \qquad R^2 = 0.9 \qquad (8)$$

$$A_6 = -0.30 \times \ln(D) + 3.86; \qquad R^2 = 0.8 \qquad (9)$$

Where, A_4, A_5 and A_6 represent the absorbance (A) of the samples having pH 4, 5 and 6, respectively. Equations 7-9 gave the regression models and the values of correlation coefficients (R^2) of the logarithmic decrease of absorbance (A) against absorbed dose (D) for high dose dosimetry; which showed their strong relationship and radiation-induced degradation of the dye.

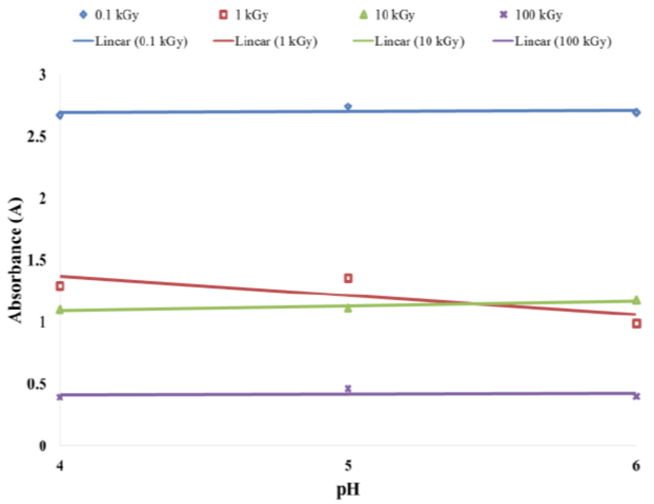

Figure 7: The effect of pH on absorbance (A) of sample solutions of SO.

$$A_{0.1k} = 0.01 \times (pH) + 2.65; \quad (10)$$

$$A_{1k} = -0.15 \times (pH) + 1.97; \quad (11)$$

$$A_{10k} = 0.04 \times (pH) + 0.95; \quad (12)$$

$$A_{100k} = 0.006 \times (pH) + 0.39; \quad (13)$$

Where, $A_{0.1k}$, A_{1k}, A_{10k} and A_{100k} represent the absorbance (A) of *acidic* samples at 0.1, 1, 10 and 100 kGy, respectively. Equations 10-13, correspond to the regression models; demonstrating the effect of pH on the absorbance (A) of the sample solutions of *SO*. The absorbance (A) could not get affected enough by the pH of the sample solutions.

NOVELTY

First time ever, we are introducing the new symbol "Đ (*pronounced as d-cut*)" for the dosimetric term "Decoloration" which has always been used as a complete word in literature. We hope scientists and many authors, working in this field, will appreciate and acknowledge it.

CONCLUSION

Sandalfix Orange C2RL (SO) dye followed Beer's law, and hence suitable for spectrophotometric studies. However, a linear behavior, to some extent, has been seen in the dosimetric calculations and a decrease in the absorbance (A) was noticed upon irradiation in the range 0.1-1 kGy and 10-100 kGy i.e., *low* and *high* dosimetry, respectively. The %decoloration (%Đ) of *SO* was increased exponentially in low dosimetry while increased logarithmically in high dosimetry with respect to absorbed dose (D). Absorbance (A) of *SO* was linearly decreased in *low* dosimetry while logarithmically decreased in *high* dosimetry with respect to absorbed dose (D). The absorbance (A) could not get affected enough by the pH of the sample solutions within the conditions given in this study.

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