Dosimetric Characteristics of Aqueous Solutions of Sandalfix Red Dye for Gamma Dosimetry

Taqmeem Hussain[1,*], Muhammad Shahbaz[2], Inam-ul-Haq[3], Hashim Farooq[3], Nasir Amin[1] and Yasir Jamil[3]

[1]*Department of Physics, GC University, Faisalabad, Punjab, Pakistan*

[2]*Punjab Institute of Nuclear Medicine (PINUM), Faisalabad, Punjab, Pakistan*

[3]*Department of Physics, University of Agriculture, Faisalabad, Punjab, Pakistan*

Abstract: Gamma dosimetric behavior of the aqueous solutions of the Sandalfix Red (C.I. Reactive Red 195A) dye was studied. The sample solutions of two chemical natures i.e., Acidic and Alkaline; were irradiated by Co^{60} γ-source in the range 0-100kGy. The "Control samples" were kept 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 565nm and 0.19×10^4 dm^3 $mol^{-1}cm^{-1}$ respectively. The absorbance (A) of the aqueous solutions was studied at the absorption band maxima (λ_{max}). It was hence found that the aqueous solutions of the Sandalfix Red C4BLN dye were able to be used as passive dosimeters in the range 10-100 kGy i.e., the sample solutions have shown radioactive exponential behavior of response in the "Intermediate and High dosimetry". However, a linear response was shown by the sample solutions in the "Low dosimetry".

Keywords: Chemical dosimeters, Sandalfix Red C4BLN dye, dosimetry, optical density (OD), radiolytic bleaching.

1. INTRODUCTION

It is an established fact that the ionizing radiations can cause chemical and physical changes in the exposed material [1-5]. The knowledge about the amount of gamma energy absorbed in the matter is known as radiation chemistry. In radiation chemistry, a quantitative estimation of the absorbed energy deals with its branch known as "Dosimetry" and the system employed to do this job is known as a "Dosimeter" [2-5]. Amount of energy absorbed from the gamma radiation with respect to the chemical changes produced in the system on exposure to the radiation is called "Chemical dosimetry", which requires calibration in order to use as dosimeter and is, therefore, termed as secondary dosimeter (passive dosimeter) [6].

The verification of the Sandalfix Red C4BLN to be used for dosimetric calculations within the gamma radiation dose range 0-1kGy was already reported [3] as this dye obeys the Beer's Law but in the present study the absorbed dose range was increased from 0-100kGy in order to observe the change in the λ_{max} and the dosimetric response of the dye with respect to the absorbed doses. The application range depends on the concentration of the dye and the solvents used [7]. Bleaching of the dye in aqueous solutions by the ionizing radiations is a known fact now and is still an active research area for many researchers of the present era to produce dosimeters which should be inexpensive, easy to handle and have the capacity to work within the high dose ranges [8]. This bleaching property of the chosen dye makes the aqueous solutions of the dye able to be used for dye-dosimetry, since the decomposition of the dye depends linearly upon the amount of dose absorbed [6, 9].

2. MATERIALS & METHODS

Aqueous solutions of Sandalfix Red C4BLN (Color Index: Reactive Red 195A, MW= 1033.5 amu) were prepared. The sample solutions of concentration 1g/L of the dye weighted by electrical balance (Sartorius Ag Gottingen BL2105, Germany) and 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=968 μmol/L and C_2=484 μmol /L. The solutions of pH 1, 2, 3, 4, 5 and 6 in the present study were termed as "Acidic Samples" and those of pH 8, 9, 10, 11, 12, 13 and 14 were termed as "Alkaline Samples" while solution of pH 7, which were kept chemically neutral and un-irradiated, were termed as "Control samples". The pH of the samples was raised and lowered using sodium hydroxide (NaOH) and hydrochloric acid (HCl) respectively. The prepared samples were preserved at room temperature (30^{o}C). The dye has absorption band maxima i.e., λ_{max}=565nm

*Address corresponding to this author at the Department of Physics, GC University, Faisalabad, Punjab, Pakistan; E-mail: relyables@yahoo.com

ISSN: 1814-8085 / E-ISSN: 1927-5129/12

determined by UV-Visible spectrophotometer (Lambda 25 1.27, PerkinElmer, USA). The absorbance (A) of the samples was measured at the λ_{max}.

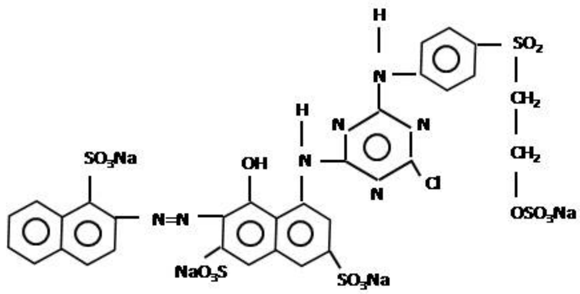

Figure 1: Structure diagram of the Sandalfix Red C4BLN dye.

2.1. Radiation Treatment of the Samples

Co^{60} gamma radiation source from Pakistan Radiation Services (PARAS) Lahore, having dose rate 400 Gy/hour was used for irradiation. Irradiation of solutions was carried out as follows: 5ml of solution was taken in a plastic vial of internal diameter 1.03 cm and thickness 0.18 cm with fit in plastic stoppers. The gamma radiation dose range was selected as 0-100kGy. Low dose dosimetry was done by the γ-radiation doses in the range of 100-1000Gy with selected doses as 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000Gy respectively. For those of intermediate doses the range of γ-radiation doses was 1-10kGy and selected doses were 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 kGy respectively. Moreover, for high-dose dosimetry, the range of 10-100kGy was chosen with the selected doses as 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100kGy 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	0.9897	0.4706
μ_4	1	1	0.9897	1	0.4737
μ_5	0	0	0.4706	0.4737	1

3. RESULTS & DISCUSSION

In order to find the λ_{max} of the Sandalfix Red C4BLN 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. Then at this λ_{max}, Absorbance of all the treated samples at each absorbed dose was measured.

Figure **2** clarifies that the scan curves of the aqueous solutions of the Sandalfix Red C4BLN dye show that the primary absorption band maxima (λ_{max}) of the un-irradiated i.e., “Control samples” and the samples radiated at the doses from 0-1000Gy have almost the same value at the abscissa 565nm.

Figure **3** explains that the scan curves of the aqueous solutions of the Sandalfix Red C4BLN dye show that the primary absorption band maxima (λ_{max}) of the un-irradiated i.e., “Control samples” and the samples radiated at the doses from 1-5kGy have almost the same value of 565nm and there is no change in λ_{max} from 0Gy to 5kGy.

Figure **4** justifies that the scan curves of the aqueous solutions of the Sandalfix Red C4BLN dye show that the primary absorption band maxima (λ_{max}) of the un-irradiated i.e., “Control samples” and the samples radiated at the doses from 6-10kGy have shifted from 565nm to 500nm in the gamma dose range of 6-10kGy. This shift in λ_{max} was due to the breakage of bonds of the dye and after this degradation of the dye molecules, the pigments in the sample solutions was lessened due to the bombardment of the gamma photons from the Co^{60} γ-radiation source.

Figure **5** elaborates that the scan curves of the aqueous solutions of the Sandalfix Red C4BLN dye. The primary absorption band maxima (λ_{max}) of the samples radiated at the doses from 10-100kGy have shifted from 500nm to the very low range of visible region as the sample solutions were containing almost no dye molecules behind upon irradiation within this high dosimetry range of 10-100kGy. This shift in λ_{max} of the dye was due to the breakage of Nitrogen double bonds (-N=N-) of the dye and after this degradation of

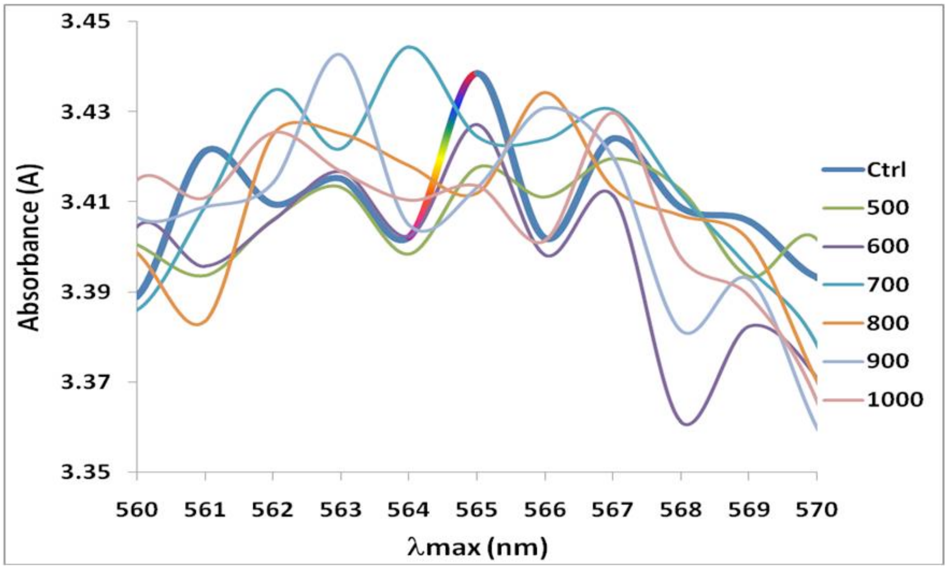

Figure 2: The determination of the absorption band maxima (λ_{max}) of Sandalfix Red C4BLN within the dose range 0-1000Gy.

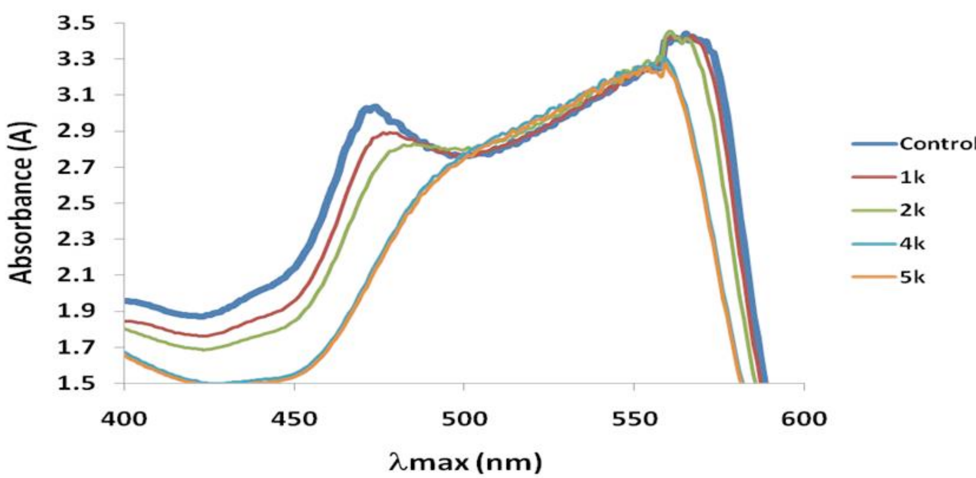

Figure 3: The determination of the absorption band maxima (λ_{max}) of Sandalfix Red C4BLN within the dose range 1-5kGy.

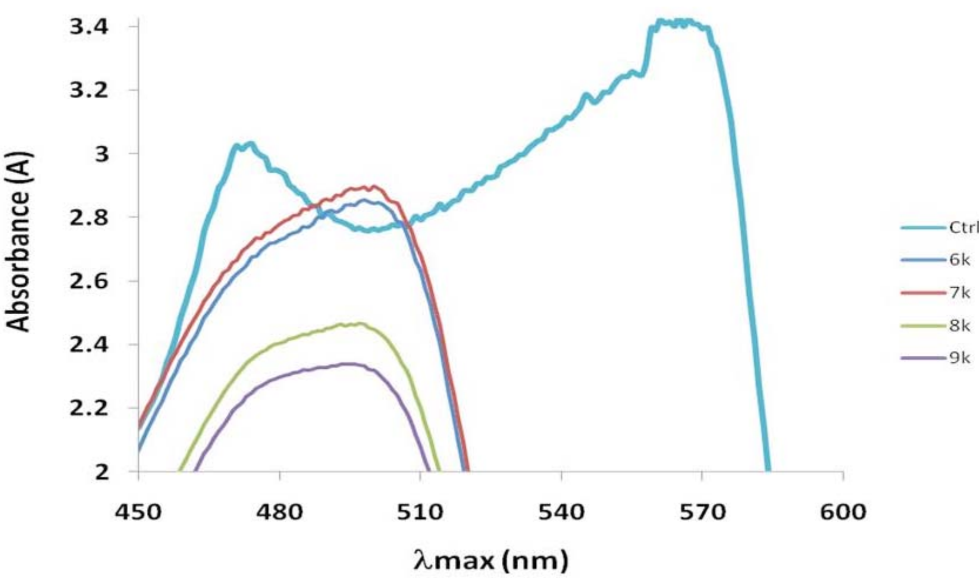

Figure 4: The determination of the absorption band maxima (λ_{max}) of Sandalfix Red C4BLN within the dose range 6-10kGy.

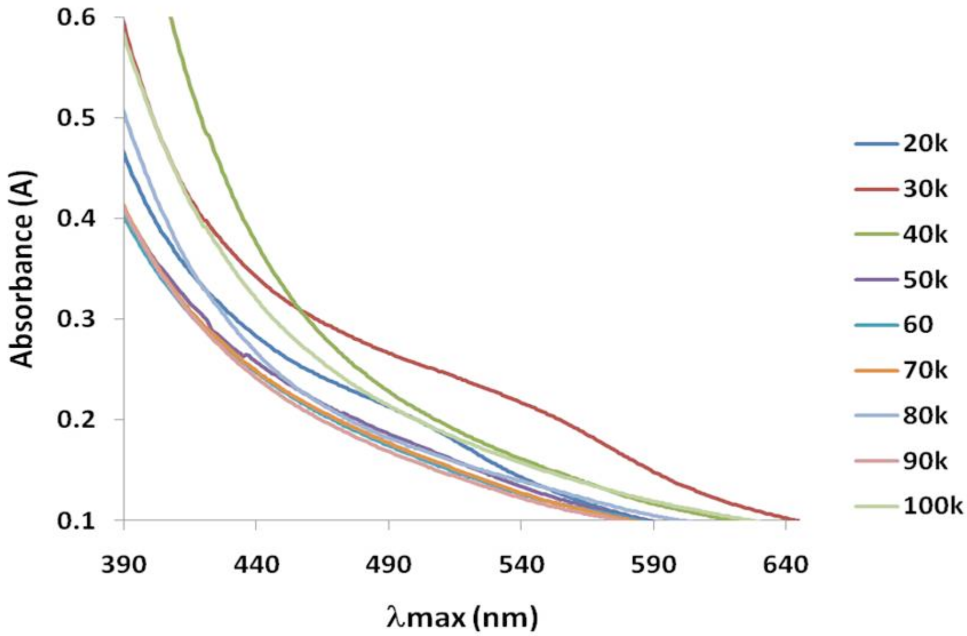

Figure 5: The determination of the absorption band maxima (λ_{max}) of Sandalfix Red C4BLN within the dose range 10-100kGy.

the dye molecules, the pigments in the sample solutions was almost finished due to the bombardment of the gamma photons from the Co^{60} γ-radiation source [3].

3.1. Low Dosimetry

The gamma radiation response for the aqueous solutions of the Sandalfix Red C4BLN in terms of the absorbance (A) as a function of the absorbed dose (D) for low-dose dosimetry is shown in Figure **6**.

$$A_{\alpha 1}= 0.0002\times D+2.9 \quad (3.1)$$

$$A_{\alpha 2}=-0.00001\times D+1.9 \quad (3.2)$$

$$A_{\beta 1}= 0.0003\times D+2.9 \quad (3.3)$$

$$A_{\beta 2}=-0.0004\times D+2.4 \quad (3.4)$$

Equations 3.1-3.2 show the curve fitting for the "Acidic samples" and Equations 3.3-3.4 show the curve fitting for the "Alkaline samples" of Sandalfix Red C4BLN of concentration C_1 and C_2 respectively, treated

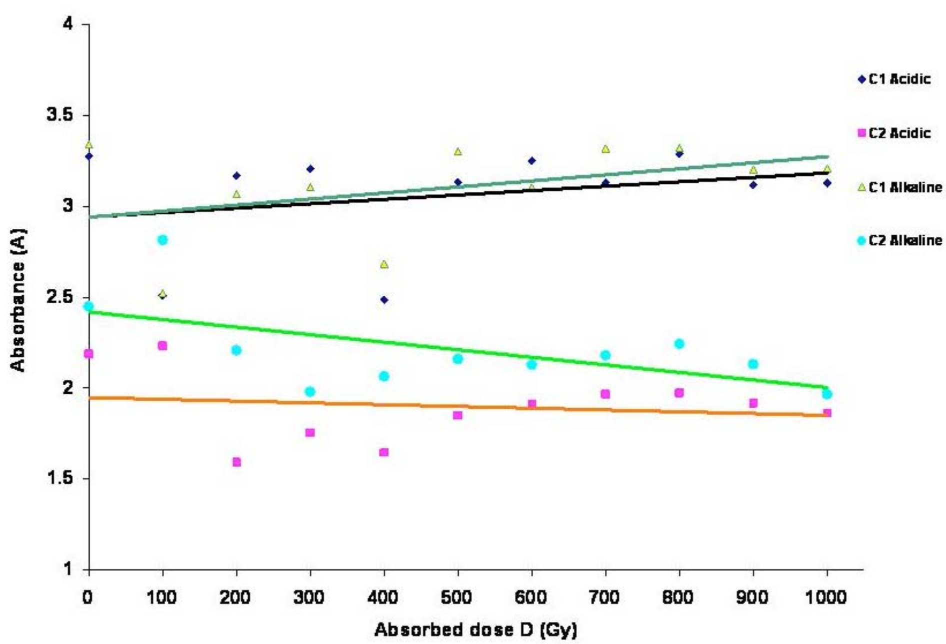

Figure 6: The decline in the Absorbance of Sandalfix Red C4BLN in dose range 0-1kGy.

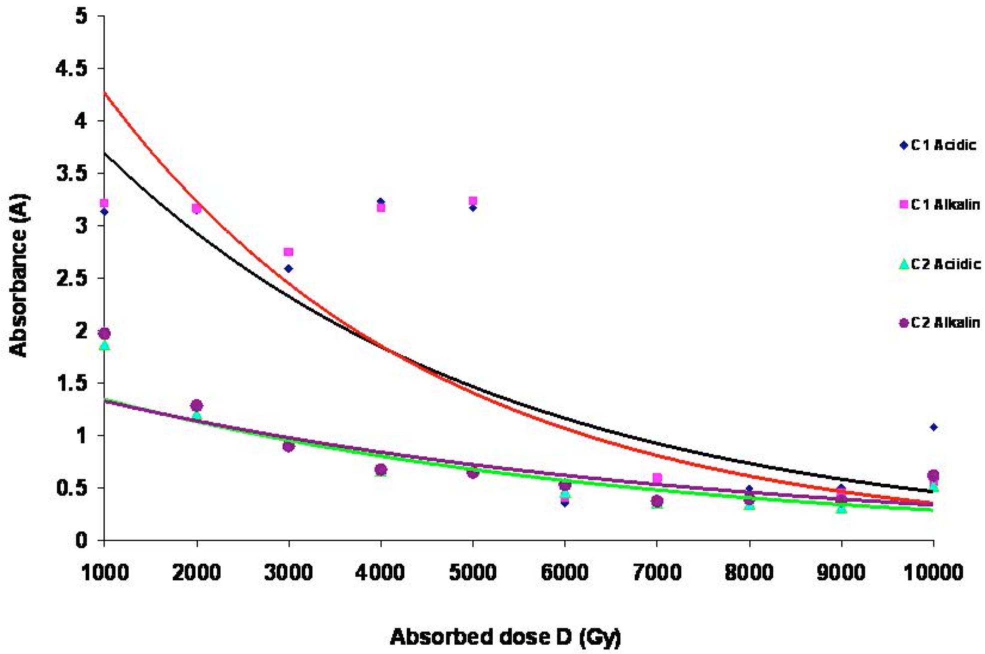

Figure 7: The decline in the Absorbance of Sandalfix Red C4BLN in dose range 1-10kGy.

at 0-1 kGy. Where, $A_{\alpha1}$ and $A_{\alpha2}$ represent the Absorbance of "Acidic samples" of concentrations C_1 and C_2 respectively and $A_{\beta1}$ and $A_{\beta2}$ represent the Absorbance of "Alkaline samples" of concentrations C_1 and C_2 respectively and D is the absorbed dose in Gy. Moreover, from equations (3.1-3.4) it is obvious that the samples of Sandalfix Red C4BLN having concentrations C_1 and C_2 showed the linear behavior of response with the absorbed dose range 0-1 kGy which was selected to be the range for "Low dose dosimetry".

3.2. Intermediate Dosimetry

The gamma radiation response for the aqueous solutions of the Sandalfix Red C4BLN in terms of the absorbance (A) as a function of the absorbed dose (D) for Intermediate-dose dosimetry is shown in Figure **7**.

$$A_{\alpha1}=4.65\times\exp(-0.0002D) \quad (3.5)$$

$$A_{\alpha2}=1.59\times\exp(-0.0002D) \quad (3.6)$$

$$A_{\beta1}=5.63\times\exp(-0.0003D) \quad (3.7)$$

$$A_{\beta2}=1.54\times\exp(-0.0002D) \quad (3.8)$$

Equations 3.5-3.6 show the curve fitting for the "Acidic samples" and Equations 3.7-3.8 show the curve fitting for the "Alkaline samples" of Sandalfix Red C4BLN of concentration C_1 and C_2 respectively, treated at 1-10 kGy. Where, $A_{\alpha1}$ and $A_{\alpha2}$ represent the Absorbance of "Acidic samples" of concentration C_1 and C_2 respectively and $A_{\beta1}$ and $A_{\beta2}$ represent the Absorbance of "Alkaline samples" of concentration C_1 and C_2 respectively and D is the absorbed dose in Gy. Moreover, from equations (3.5-3.8) it is obvious that the samples of Sandalfix Red C4BLN having concentrations C_1 and C_2 showed the exponential behavior of response with the absorbed dose range 1-10 kGy which was selected to be the range for "Low dose dosimetry".

3.3. High Dosimetry

The gamma radiation response for the aqueous solutions of the Sandalfix Red C4BLN in terms of the absorbance (A) as a function of the absorbed dose (D) for High-dose dosimetry is shown in Figure **8**.

$$A_{\alpha1}=0.83\times\exp(-0.000009D) \quad (3.9)$$

$$A_{\alpha2}=0.33\times\exp(-0.00002D) \quad (3.10)$$

$$A_{\beta1}=0.35\times\exp(-0.000004D) \quad (3.11)$$

$$A_{\beta2}=0.31\times\exp(-0.00002D) \quad (3.12)$$

Equations 3.9-3.10 show the curve fitting for the "Acidic samples" and Equations 3.11-3.12 show the curve fitting for the "Alkaline samples" of Sandalfix Red C4BLN of concentration C_1 and C_2 respectively, treated at 10-100 kGy. Where, $A_{\alpha1}$ and $A_{\alpha2}$ represent the Absorbance of "Acidic samples" of concentration C_1 and C_2 respectively and $A_{\beta1}$ and $A_{\beta2}$ represent the Absorbance of "Alkaline samples" of concentration C_1 and C_2 respectively and D is the absorbed dose in Gy.

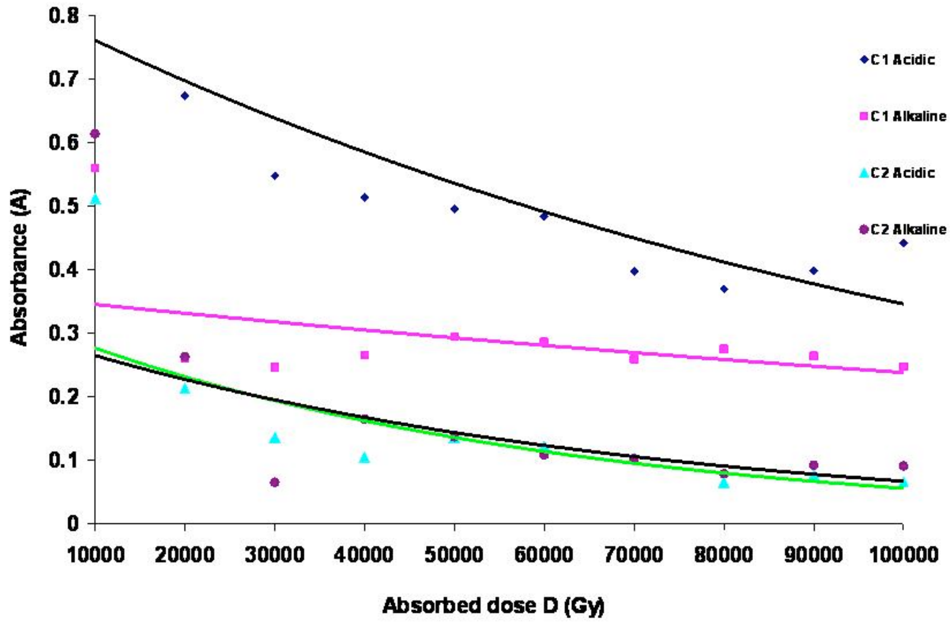

Figure 8: The decline in the Absorbance of Sandalfix Red C4BLN in dose range 10-100kGy.

Moreover, from equations (3.9-3.12) it is obvious that the samples of Sandalfix Red C4BLN having concentrations C_1 and C_2 showed the exponential behavior of response with the absorbed dose range 10-100 kGy which was selected to be the range for "High dose dosimetry".

3.4. The Correlation Coefficients

Table **1** represents the parameters of the study whereas Table **2** shows the matrix of correlation coefficients between 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_4 and μ_5 with μ_6 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 Sandalfix Red C4BLN was found for both the concentrations i.e., C_1=968 μmol/L and C_2=484 μmol /L and is shown in the Table **3** below.

4. CONCLUSION

Consequently, the aqueous solutions of the Sandalfix Red C4BLN dye were able to be used as passive dosimeters in the range 10-100 kGy i.e., they have shown very good response in the "Intermediate and High dosimetry" rather than "Low dosimetry". Table 3 shows the found values of molar extinction coefficient ε for each concentration and also for each chemical nature and it was on average 0.19×10^4 $dm^3\ mol^{-1}cm^{-1}$ 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 565nm, however, it was found to decrease from 565nm to 500nm in the ranges 1-10kGy and finally, in the High dosimetry, 10-100kGy, no value of λ_{max} of the dye was found within the visible region of the

Table 3: Matrix of the Correlation Coefficients Between the Parameters (Variables) of the Study

Concentrations	Sample type	Molar Extinction Coefficient ε ($dm^3\ mol^{-1}cm^{-1}$)
Concentration (C_1)	Acidic samples (A_α)	0.18×10^4
	Alkaline samples (A_β)	0.18×10^4
Concentration (C_2)	Acidic samples (A_α)	0.19×10^4
	Alkaline samples (A_β)	0.22×10^4

electromagnetic spectrum due to breakage of the pigments of the dye molecules. The absorbance (A), being the dosimetric response of the dye, has shown linear relationship with the absorbed dose (D) for both the concentrations C_1 and C_2 in the "Low Dosimetry" but have shown exponential behavior in both the "Intermediate and High dosimetry" which indicated that the selected dye was not fit for "Low dosimetry" but the best dose ranges for the dosimetric purposes of the selected dye should be 1-10kGy. 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.

ACKNOWLEDGEMENTS

Special thanks to the Director, Punjab Institute of Nuclear Medicine (PINUM), Faisalabad for providing the laboratory facilities and to Mr. Kafayat-Ullah, Pakistan Radiation Services (PARAS), Lahore, for providing the radiation facility because without their help the present effort becomes meaningless.

REFERENCES

[1] Nasef BEA, Yun-Dong C, Walker ML, Sheikhly MA, Mclaughlin WL. Anionic triphenylmethane dye solutions for low-dose food irradiation dosimetry. J Radiat Phys Chem 1995; 46:1189-97. http://dx.doi.org/10.1016/0969-806X(95)00353-Y

[2] Hussain MY, Shad NA, Nasim-Akhtar, Ali S, Hussain T, Inam-ul-Haq. Commercial SFG Yellow CRL dye aqueous solutions for gamma dosimetry. Pak J Agric Sci 2009; 46(1): 78-81.

[3] Hussain MY, Islam-ud-Din, Hussain T, Nasim-Akhtar, Ali S, Inam-ul-Haq. Response of Sandalfix Red C4BLN dye solutions using Co^{60} γ-Radiation source at intermediate doses. Pak J Agric Sci 2009; 46(3):224-27.

[4] Hussain T, Shahbaz M, Inam-ul-Haq, Farooq H. Radiolytic reduction of aqueous solutions of a commercial reactive dye in the range 0-100kGy by Co^{60} gamma radiation source. J. Basic & Appl Sci 2012; 8:280-285.

[5] Hussain T, Hussain MY, Shahbaz M, Inam-ul-Haq, Farooq H, Ali S. Radiolysis of commercial dyes in aqueous solutions to produce dosimeters for gamma dosimetry. J. Basic & Appl Sci 2012; 8:315-318.

[6] Parwate DV, Sarma ID, Batra RJ. Preliminary feasibility study of congo red dye as a secondary dosimeter. Radiat Meas doi:10.1016/j.radmeas. 2007; 03.002.

[7] Emi RG, Andras K, Fletcher JJ. Dosimetry characterization of tetrazolium violet-polyvinylalcohol films. J Radiat Phys Chem 2007; 76: 1519-22. http://dx.doi.org/10.1016/j.radphyschem.2007.02.064

[8] Khan HM, Anwer M, Chaudhry ZS. Dosimetric characterisation of aqueous solution of brilliant green for low-dose food irradiation dosimetry. J Radiat Phys Chem 2002; 63: 713-17. http://dx.doi.org/10.1016/S0969-806X(01)00640-5

[9] Ebraheem S, Beshir WB, Eid S, Sobhy R, Kov AA. Spectrophotometric readout for an alanine dosimeter for food irradiation applications. J Radiat Phys Chem 2003; 67: 569-73. http://dx.doi.org/10.1016/S0969-806X(03)00107-5

Received on 12-07-2012 Accepted on 09-08-2012 Published on 06-09-2012

http://dx.doi.org/10.6000/1927-5129.2012.08.02.30