INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 1, JANUARY-2014
ISSN 2229-5518

Optical and Mechanical Properties of PVA Films using Spectrophotometry & XRD Techniques

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Abstract: Polyvinyl-alcohol based reactive red 195-A films (PVA-R) were irradiated by Cs^{137} γ-source in the range of 200 Gy-10^5 Gy. The effects of gamma irradiation on optical and mechanical properties of PVA-R were studied using spectrophotometry and x-ray diffraction (XRD) technique to check its feasibility in radiation processing. The found values of the λ_{max} and the molar extinction coefficient of the dye were 520 nm and 48 $Lgm^{-1}mm^{-1}$ respectively. Parameters such as effect of dye concentration and pH values, Electrical Conductivity, % decoloration, Strain , % crystallinity, crystallinity Index (C.I.) and crystallite size (d) have been selected for the dosimetric and mechanical strength evaluation. Linearity between specific absorbance and absorbed dose showed that acidic samples of PVA-R films can be better chemical dosimeter as compared to alkaline ones in dose range of 200 Gy-10 kGy. At high dose i.e., 100 kGy of gamma irradiation, change in mechanical strength was found due to decrease in crystallinity, crystallite size and increase in strain values.

Keywords: **Polyvinyl Alcohol, Reactive Red 195-A, gamma irradiation, Specific Absorbance, XRD, Crystallinity.**

1 INTRODUCTION

The chemical, biological and physical effects of radiation on materials are scientific establishment of the radiation technology [7]. A systematic attempt to measure such radiations is known as dosimetry and has become an active research area for scientists of the present era. One of the most effective and economical attempt of the researchers to design, manipulate, fabricate or to develop dosimeters in chemical dosimetry was to use dyes in form of their solutions[3], gels [4] or films [1,2]. Radiochromic films instantly changes color upon exposure to ionizing radiation and needs no chemical or physical process. Radiochromic dosimeters are prepared using different natural or artificial dyes and polymer materials. Artificial dyes are preferable over natural dyes due to their tincture strength, vast color range and good fastness properties, mainly, to ultraviolet light and different chemical and detergents. The first and foremost step to check the confirmation of the dosimetric calculations of any proposed material is Beer's Law which is related to the absorption of light (A) with respect to the concentration(c) of dye present in solution and the thickness of material(l) as given by following equation 1.

$$A = \varepsilon c l \quad (1)$$

Where ε is a constant known as molar extinction coefficient.

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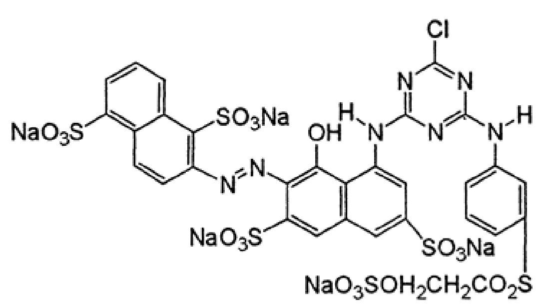
The dosimetric response of reactive red in aqueous solutions has been determined [5] in the range limit of 0 Gy-100kGy, present study aims at to check out its response in PVA films. Moreover the use of high-energy radiation incident on polymer films may support the development of mechanically strong polymers [9]. One of the resulting processes of radiation interaction in polymers is crosslinking which usually enhance the mechanical strength, environmental stability and radiation stability [15]. In order to check such changes, the calculations were made from continuous scans obtained from XRD; a best technique to study such mechanical changes along with the crystallinty and grain size of the sample under observation for dosimetric calculations. The overall objective of this work is to check for reactive yellow 145-A to respond to Gamma radiation as a dosimeter. Furthermore, the mechanical properties and morphological features will be obtained for un-irradiated and irradiated PVA-R films using XRD to understand the overall effect of irradiation on the sample. The molecular structure of reactive yellow 145-A is shown in Fig 1.



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ISSN 2229-5518

Figure 1. Molecular structure of reactive red 195A

2 MATERIALS AND METHODS

Films were prepared by adding 3g of PVA in 50 ml distilled water [12] and was kept well stirred at a temperature of 60^0C followed by continuous stirring for 1hr at room temperature to make a homogeneous mixture. Three concentrations i.e., 1g/L, 0.5g/L and 0.25g/L of dye was dissolved in PVA solution until the formation of a uniform dyed solution [13]. pH of PVA-R solutions was adjusted with the help of NaOH and HCl to get the samples of three different chemical natures i.e., acidic, alkaline and neutral (measured by pH-meter (3510 pH-meter (Jenway)) [11]. Electrical conductivity (EC) of all acidic and alkaline solutions was also measured using EC meter (KL-1388) which was found to be 1100μScm^{-1} and 1330 μScm^{-1} respectively. 0.5ml PVA-R dyed solution was poured every time on a perfectly leveled horizontal glass plate for casting of film and let it to be dried for almost 48 hrs at room temperature. Uniform films having thickness of 0.03mm were obtained after detaching from glass plate, were stored at room temperature in dark, sealed in small dark plastic bags and stored under 1aboratory condition for further investigations [6]. Irradiation was carried out with the Mark-IV irradiator (Cs^{137}gamma ray source) having dose rate of 660Gy/h, confirmed by Fricke reference standard dosimeter prior to every run of film irradiation [8]. Range of dosimetry was characterized as low dosimetry (0-1 kGy), intermediate dosimetry (1-10 kGY) and high dosimetry (10-100kGY). The absorption band maxima (λ_{max}) of dye was explored using a UV/VIS spectrophotometer (Perkin Elmer Precisely Lambda 25 UV/VIS) and optical density of all films was find out at this λ_{max} for pre and post irradiation. The X-ray diffraction studies were carried out using diffractometer available at QU, Islamabad, Pakistan. % crystallanity, crystallanity index (C.I), stress and strain were calculated using following equations.

$$\% \text{ Crystallanity} = \frac{I_{max}}{I_{max} + I_{min}} 100 \qquad (2)$$

$$\text{Crystallanity index} = \frac{I_{max} - I_{min}}{Imax} \qquad (3)$$

$$\eta = \frac{B\cos\theta - K\lambda/d}{\sin\theta} \qquad (4)$$

$$\varepsilon = \frac{B\cos\theta}{4\tan\theta} \qquad (5)$$

The working conditions of XRD used are shown in table 1.

Table 1.working conditions of XRD

X-radiation	NI-filtered
X-ray tube voltage & current	35kV& 20mA
Divergent & Anti-scatter slits	1^o
Receiving slits	0.13mm & 0.3mm
Goniometer Scanning speed/step width	$1^o min^{-1}/0.02^o$
Ratemeter time constant	1s
Detector	Scintillation counter
Start angle	^{70o}(2)
Stop angle	^{5o}(2)

3 RESULTS AND DISCUSSION

Spectrophotometric analysis

The spectrophotometric analysis and gamma radiation response for Reactive Red 195A in PVA films were studied in three phases of the dosimetry i.e., Low dosimetry (0 Gy–1 kGy), Intermediate dosimetry (1 kGy-10 kGy) and High dosimetry (10 kGy-100 kGy). Moreover, XRD technique was used in order to know the morphological changes in the films exposed to gamma radiations. Following is the scientifically and technically detailed discussion of the acquisited data and the results obtained for the selected dye. Absorption spectra of unirradiated and irradiated solutions were recorded in the range of 380-700nm. An absorption band maximum (λmax) for controlled samples was found to be 520nm. Radiation induced color changes found in PVA-R films indicated its structural changes. To study the effect of pH on the dosimetric response of the films; two sets of the films having pH 4 and 10 were prepared and were exposed to gamma radiations. Maximum

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 1, JANUARY-2014
ISSN 2229-5518

decoloration for PVA-R films was found to be 74 % in acidic samples. %Decoloration was calculated by using following equation.

$$\% \text{ Decoloration} = \frac{A_o - A_i}{A_o} \times 100 \quad (6)$$

Where A_0 and A_i are the absorbances of the dyes before and after irradiation (Wang et al., 2006).

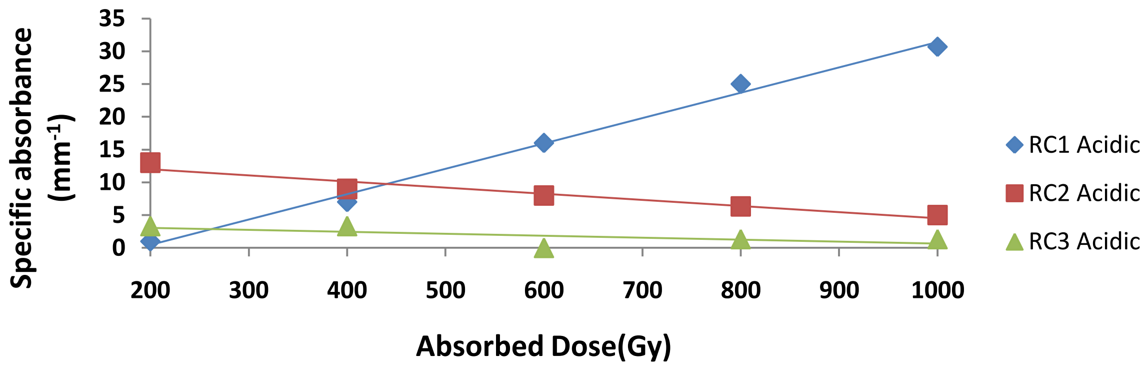

Figure 2.The dosimetric response of PVA-R acidic in dose range 200Gy-1kGy

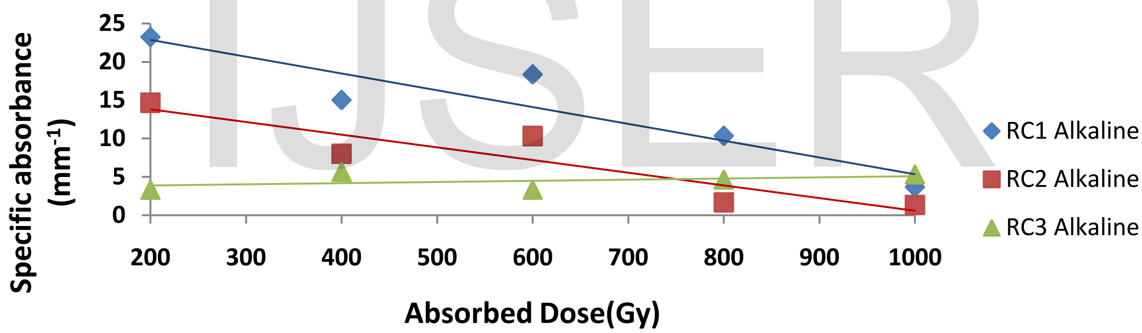

Figure 3. The dosimetric response of PVA-R alkaline in dose range 200Gy-1kGy

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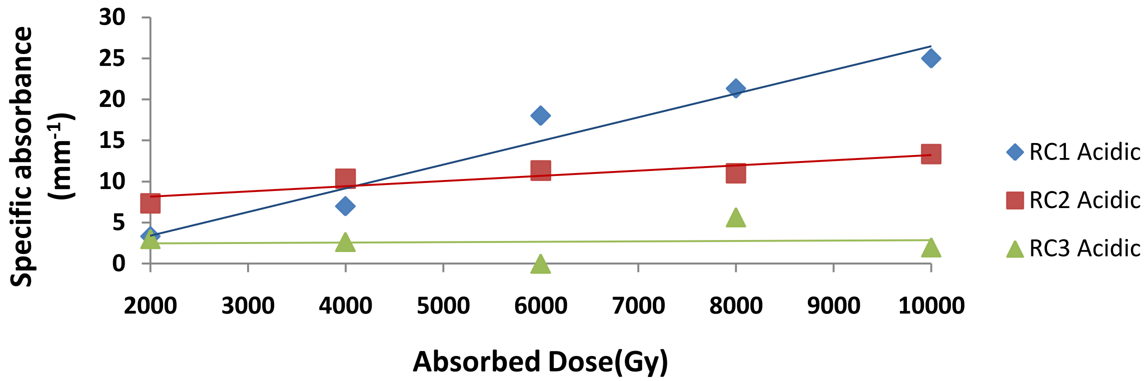

Figure 4.The dosimetric response of PVA-R acidic in dose range 2 kGy-10 kGy

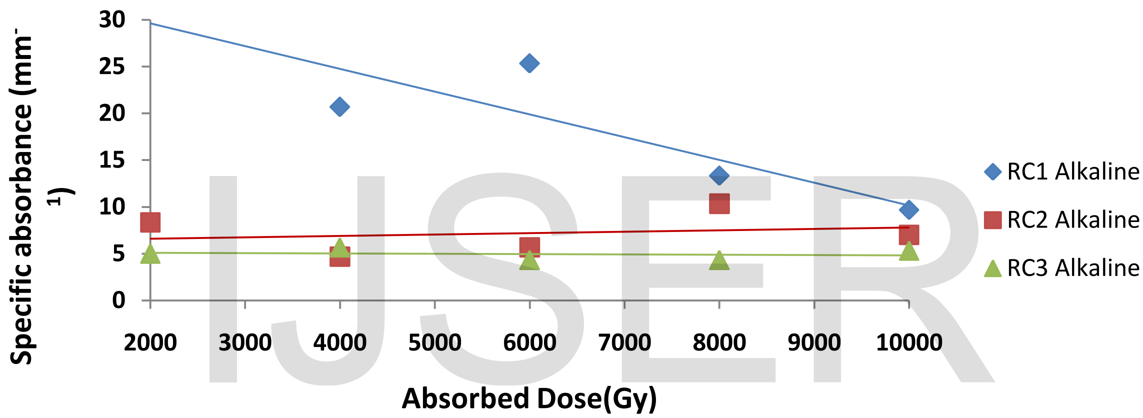

Figure 5. The dosimetric response of PVA-R alkaline in dose range 2 kGy-10 kGy

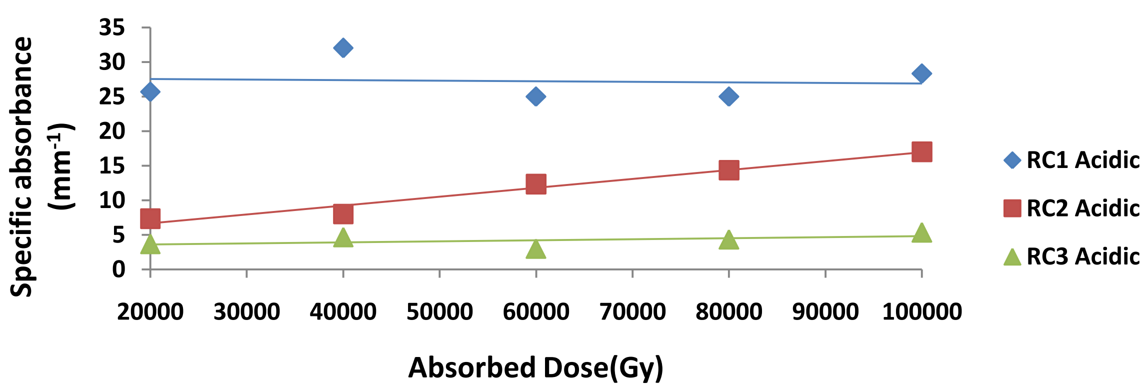

Figure 6: The dosimetric response of PVA-R acidic in dose range 20 kGy-100 kGy

Low Dose Range

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Figures 2 and 3 describe the specific absorbance at λ_{max} of irradiated acidic and alkaline films respectively, against absorbed dose 200 Gy-1 kGy. All PVA-R samples show linear response with almost a negligible variation in low dosimetry phase. A deep look on figures permits to claim that the highly concentrated samples show ideal dosimeteric response for gamma radiation as compared to the light concentrations. Lower concentrations were insensitive to gamma radiation response. Moreover, the acidic samples show better dosimetric response as compared to alkaline samples.

Intermediate Dose Range

A deep look on Figure 4, describes that Among all acidic samples of reactive red 195 A, it was found that for intermediate dose range specific absorbance of C_1 concentration sample ideally increased linearly with absorbed dose providing good dosimetric response as compared to other concentrations, proving the feasibility of the narrated dye to be used as dosimeter in this specified range. Response curves of alkaline samples of reactive red 195 A was not as good as those of acidic. C_2 and C_3 exist in saturation region. It was found that for intermediate dose range specific absorbance of different alkaline samples could not provide good dosimetric response.

High Dose Range

Figures 6 shows the specific absorbance at λ_{max} of irradiated acidic films respectively, against absorbed dose 2 kGy-10 kGy. Among all acidic samples of reactive red 195 A, it was found that At high dose range C_1 and C_3 sample comes in the saturation region providing the fact that red dye sample of C1 can be a good dosimeter below this high dose range while curve fitting C2 shows good response in this high dose range.

X-ray Diffraction (XRD)

X-ray diffraction (XRD) is a new technique planned to be used in routine dosimetry in order to notice the optical and structural properties of gamma irradiated PVA films, therefore, the parameters like Stress (**η**), Strain (ε), Modulus of Elasticity (Y), % Crystallinity, Crystallinity Index (C.I.) and Crystallite Size (d) have been selected for the dosimetric evaluation. From XRD pattern Figures 8 for PVA-R, the crystallinity has been evaluated on behalf of the assumption that broadening of line is due to the increase in amorphousness whereas if crystallinity increases it results into the increase in peak intensity.

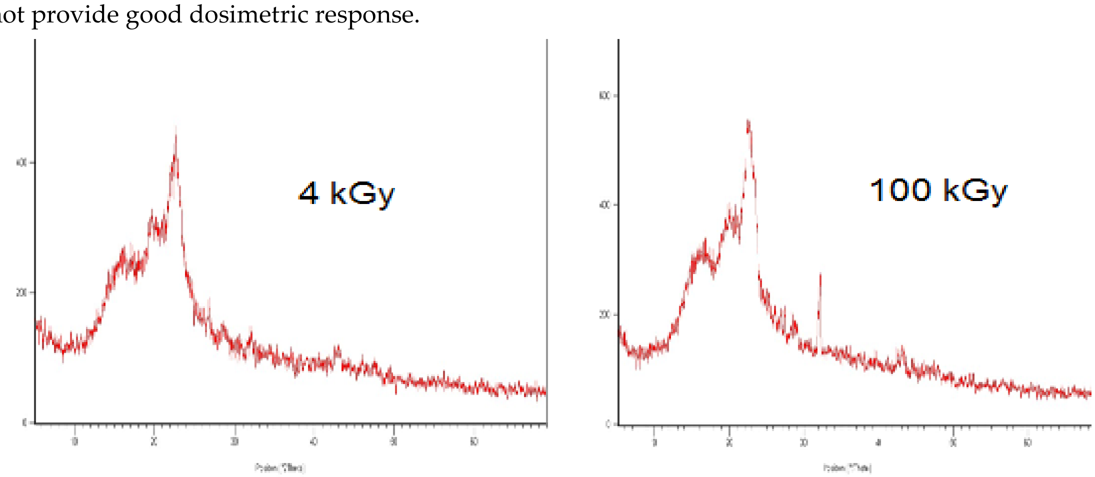

Figure 7. XRD pattern of PVA-R at two different doses

Table 2, for PVA-R increase in the absorbed dose resulted into increase in intensity, which indicates the change in crystallinity in this material. Other measurements like crystallite size, FWHM, %

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crystallinity indicated that for PVA-R amorphousness has been increased. This change in diffraction peaks intensity may be due to the destruction of the original structure of PVA films.

Table 2.Mechanical properties and crystallinity from XRD pattern for PVA-R

Properties	**PVA-R**	
	4 k Gy	**100 kGy**
% crystallanity	63%	62%
FWHM (degrees)	2.25	2.5
Crystallie size d (nm)	4.0	3.8
Stress η (Nm^{-2})	$-9.7 X 10^{-8}$	$-9.8 X 10^{-8}$
Strain ε	2.79	3.0
Modulus of ElasticityY (Nm^{-2})	$3.4 X 10^{-8}$	$3.2 X 10^{-8}$
Intensity (a.u)	450	550

4 CONCLUSION

Radiation induced color changes found in PVA-R films indicated their structural changes. Effect of concentration, absorbed dose and pH for PVA-R showed that highest concentration provided good dosimetric response for low and intermediate dose range while for high dose ranges such PVA films could not provide good dosimetric responce. From XRD pattern obtained calculations for decrease in crystallinity, small crystallite size, less peak broadening and strain values in PVA-R after gamma irradiation proved that this dosimeter has less mechanical strength as compared to unirradiated PVA-Y film.

ACKNOWLEDGMENT
Special thanks to Director, NIAB Faisalabad for providing the irradiation and laboratory facilities and Dr. Nasim Akhtar, DCS, NIAB Fsd for inspiring guidance and valuable suggestions during the span of this research work.

5 FUTURE PROSPECTS
Radiochrmic film dye dosimetry is an active area of research which should be accompanied with the efforts to make it ecologically safe and less damaging for human health. By using different dose ranges and eco-friendly textile industrial procedures radiochromic film dye dosimetry can be used for proper dose delivery check up, enhancement of shelf life, sterilization and pasteurization and waste management techniques. The above said future objectives will only be achieved by getting proper knowledge of radiation protection and safety, documentation and dose assessment techniques.

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