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The use of polyvinyl chloride films dyed with methyl red in radiation dosimetry

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▶ ***Technical note***

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ABSTRACT

Background: The purpose of this work was to investigate the use of polyvinyl chloride (PVC) dyed with methyl red as a high dose radiation dosimetry. ***Materials and Methods:*** Commercial PVC films from Sabic made from resins PVC57S with thickness of 60 µm and methyl red with a molecular weight of 269.31 were used. Irradiation was carried out using a ^{60}Co γ-ray generator with sources arranged in rectangular holder with a total activity of 73.6926 kCi. Absorbance measurements were made by Jasco V- 630 UV-VIS spectrophotometer. Dose rate and irradiation temperature effects as well as post-irradiation storage in dark and indirect daylight conditions on dosimetry performance were also investigated. ***Results:*** The results showed a linear relationship between the relative absorbance (response) and the absorbed dose at the wavelength 548 nm in the range of 0-150 kGy. The response was found to be independent of both dose rate and irradiation temperature. ***Conclusion:*** The experimental results indicate that PVC films dyed with methyl red may be used for a high dose radiation dosimetry.

Keywords: *Polyvinyl chloride, gamma radiation, methyl red, dosimetry.*

INTRODUCTION

Dosimetry plays an important function in the quality control of radiation processing (1). Radiochromic films dosimeters based on the radiation-induced color bleaching of organic dyes have been extensively investigated for high radiation dose dosimetry (2-7) and also in radiotherapy (8). Clear polyvinyl chloride (PVC) films were investigated (9), but there are only a few articles published about the use of PVC as a dosimeter for gamma radiation. Khan and Ahmad (10) reported that undyed PVC films with thickness of 1 mm were useful as gamma radiation dosimeters in the range of 1-30 kGy, and were stable for up to 30 days after irradiation. Radiation-induced color bleaching of PVC films containing malachite green and bromocresol purple dyes were investigated as high-dose radiation dosimeters in the dose ranges of 0-125 kGy (11) and from 0 to 50 kGy (12), respectively. The effect of gamma radiation on the organic dye methyl red and its possible use in chemical dosimetry was investigated (13). The useful dose range of aqueous solution of methyl red in alkaline was between 50 and 6000 Gy. Radiation-chromic film based on polyvinyl butyral (PVB) dyed with methyl red was investigated as a high dosimeter (14) in the range up to 150 kGy.

The aim of this study was to use polyvinyl chloride PVC films dyed with methyl red as a high dose dosimeter. Since radio-chromic films used in routine dosimetry systems are usually influenced by the environmental conditions such as irradiation time, dose rate, shelf life and post irradiation time, this study investigated the effect of these parameters on the dose range up to 150 kGy.

MATERIALS AND METHODS

Films preparation

Commercial PVC films from Sabic made from resins PVC57S with thickness of 60 µm, and methyl red with a molecular weight of 269.31 g/mol (Merck, Germany) were used. The chemical structure of methyl red is shown in figure 1.

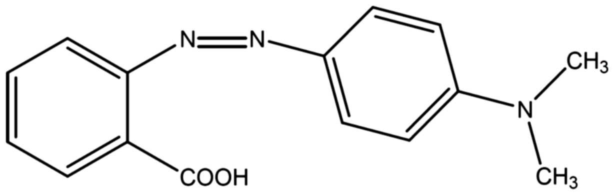

Figure 1. Molecular structure of methyl red.

The dying process was carried out by washing PVC films with dimension of 2 × 2 cm^2 and one thickness (60 µm) with ethanol. Drying was carried out at room temperature for 2 h. Dried films of 60 µm were immersed in 1g/L of methyl red in acetone solution, for one second, at 25 °C. After dying, PVC films were dried at room temperature in darkness, and after drying they were stored in darkness. The temperature of the dye solution plays an important role in the dying process. Therefore, the dying process was carried out at different temperatures and the results showed a linear increase in absorbance at 548 nm with the temperature as a result of increasing the dye intensity.

In the present work, the films dying were performed at temperature of 25 °C because the dying at higher temperature makes the films surface wavy and loses transparency at temperature of 30 and higher. The variation in absorbance temperatures within the same group of films dyed at ambient temperature and for the same time period at one standard deviation was 4%.

Irradiation and measurements

Irradiation was carried out using a ^{60}Co gamma generator (Russian design type ROBO) with sources arranged in rectangular holder with a total activity of 73.6926 kCi. Dose rates of 4.56, 8.194 and 16.477 kGy/h were used for doses up to 150 kGy. All positions used for irradiation were calibrated using Fricke reference standard dosimetry system [15]. Irradiation in air was carried out in polyethylene boxes of 3 mm thickness to obtain secondary charged particle equilibrium conditions. Irradiation at different temperatures was achieved using thermostatic chamber, except for 0 °C in which a water bath containing a mixture of ice and distilled water was use, using 3 repeats for each chosen dose. Absorbance measurements were made by Jasco V- 630 UV-VIS spectrophotometer.

Statistical analysis

Analysis of the obtained results was done by using Origin9.1 software choosing linear fit for absorbance against absorbed dose, and error bars the standard deviation of three repeats were used.

RESULTS AND DISCUSSION

Absorption spectra

The absorption spectra for the PVC dyed films were recorded before and after irradiation. Figure 2 shows the absorption spectra of the unirradiated films as well as ones irradiated to different doses. There was one absorption band with a maximum at 548 nm at all doses. The spectra also showed that there was bleaching of the dye around of maximum wavelength as the absorbed dose increased. Therefore, the wavelength of the maximal absorption appeared to be suitable for dosimetric characterization; thus was used it in this study.

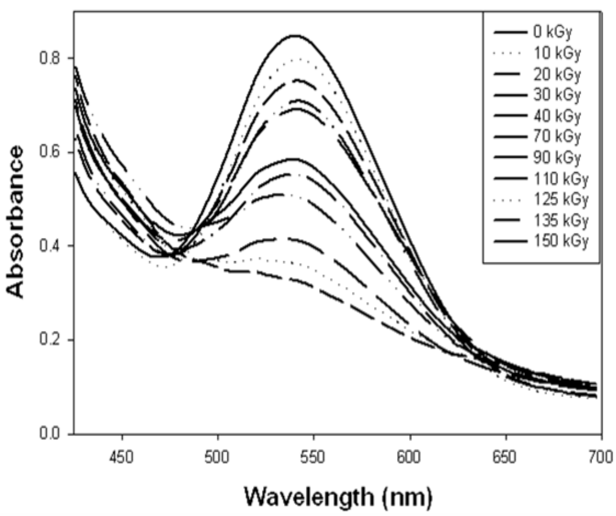

Figure 2. Absorption spectra of unirradiated as well as irradiated films to different absorbed doses.

Response curve

Three replicates of films were irradiated in air at room temperature for each studied dose; in the dose range between 0 and 150 kGy (dose rate of 16.477 kGy/h); the relative absorbance at 548 nm $(\Delta A/A_0)_{548}$ were measured, where A, A_0 are the absorbance of irradiated and non-irradiated films, respectively. Figure 3 presents a linear regression expression of the three response lines, which is derived by the formula $D=184.125\ (\Delta A/A_0)_{548}$.

It is clear that there was a good linearity up to 150 kGy of absorbed dose. Above that dose, the response tends to saturate. Irradiated undyed PVC films became dark at the high doses as a result of formation of double bonds along the chain. For this reason, it may result in a decrease of sensitivity of dosimeters over the applicable range of doses for up to 150 kGy. The estimated dose from the above relationship, to be significant, a measurement of absorbance and dose estimation shall be accompanied by an estimate of the uncertainty in the measured value. According to Ebraheem *et al.* [16], factors contributing to the total uncertainty may be separated into two types. The first is associated mainly with the measuring equipment and the films, whereas the second type is mainly related to the calibration. The reproducibility of the Jasco V-630 UV-VIS spectrophotometer was determined and it was found that the coefficient of variation (1s/rm) was 1%, indicating the precision of the spectrophotometer. The uncertainty of the thickness value of the films was found to be 1%. The uncertainty of the irradiation dose as a result of the reproducibility of the irradiance meter, stop watch and handling was found to be 2%. The error of the stability of gamma source of the geometry is assumed to be 2%. The reproducibility of the measurement of the several films (10 times for each film) was found to be 1%. The uncertainty arising during calibration over the useful response range was found to be 4%. Therefore, the combined uncertainly was determined at one standard deviation (1σ) and it was found to be ±5%.

Effect of irradiation temperature

Effect of irradiation temperature on the response of dyed films was studied by irradiation of six batches of three replicates of each at 80 kGy, dose rate of 16.477 kGy/h at six different temperature values (0, 20, 30, 40, 50, 60 °C) using controlled thermostat within ±1 °C precision, except for 0 °C in which a water bath containing a mixture of ice and distilled water was used. After irradiation, all samples were measured at 548 nm. Change of absorbance (ΔA) was calculated, and the results are presented in figure 4.

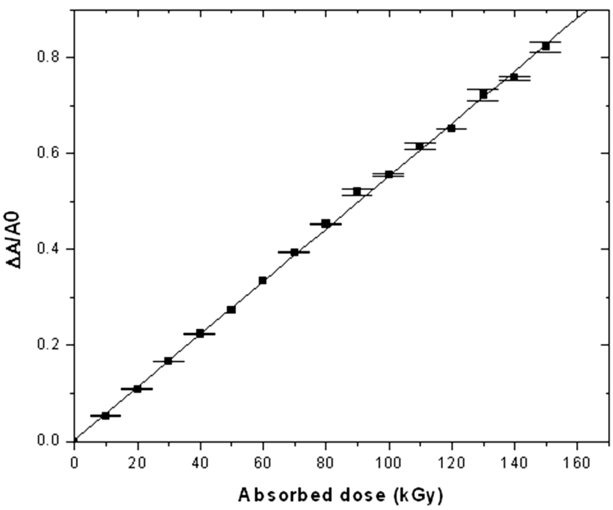

Figure 3. $\Delta A/A_0$ response curve of PVC dyed films irradiated with different dose.

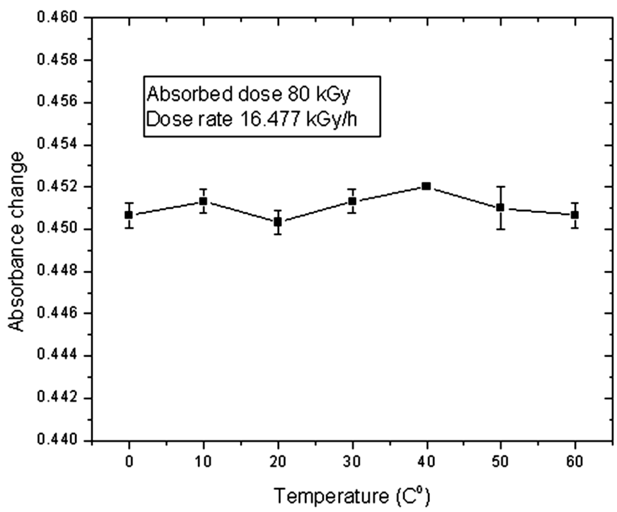

Figure 4. Dependence of the absorbance change stability of PVC dyed films on the irradiation temperature.

The responses of these types of films were found to be independent of the irradiation temperature in the range of 0–60 °C. This result is in agreement with previous works [10, 11].

Effect of dose rate

The effect of dose rate on the dose response of dyed films was studied at three dose rates (4.56, 8.194, 16.477 kGy/h) for different doses up to 150 kGy. The relative absorbance ($\Delta A/A_0$) at 548 nm was calculated and presented in figure 5.

The dose response of three dose rates followed the same behavior up to 150 kGy and showed similar linear relationship D=184.125 $(\Delta A/A_0)_{548}$. This means that the studied films were independent of dose rate within the studied range of dose rates.

Pre-irradiation stability (shelf life)

Stability measurements before irradiation of the dyed films were made by storing films in darkness and in light at ambient temperature. In addition, reading the films spectrophoto-meterically at different times during the pre-irradiation storage period of more than 1 month is shown in figure 6.

It can be seen that absorbance of dark storage films showed no change of absorbance during more than 2 months of storage. Therefore, films stored in light showed slight decrease in absorbance.

Post-irradiation stability

The effect of storage conditions on the post-irradiation stability was investigated. Two batches of three replicates were irradiated to 100 kGy and kept at room temperature at two conditions, one in darkness and the other in day light. Measurements at 548 nm were carried out periodically during the period of storage. Figure 7 shows the changes of absorbance during storage.

It was noticed that the irradiated films enjoyed good stability in darkness, were the change of absorbance during the storage period fall within 2% of doses absorbance change, which means that the dyed film had a high post-irradiation stability. However, the changes of absorbance after irradiation during the storage in day light was very clear during the first 7 days of storage, then it stabilized well over the following up period.

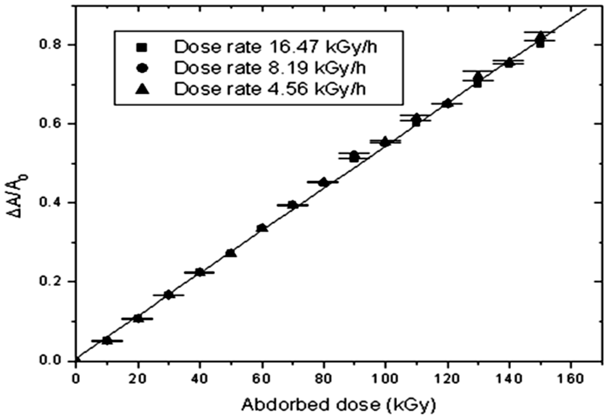

Figure 5. $\Delta A/A_0$ Response of PVC dyed films irradiated with different dose rates.

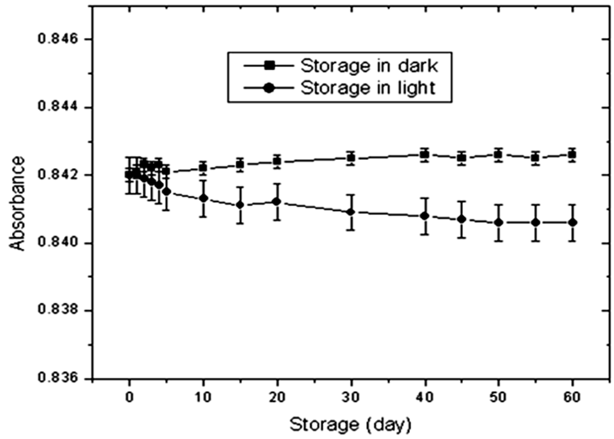

Figure 6. Shelf- life of PVC dyed films stored in dark and in daylight at ambient temperature.

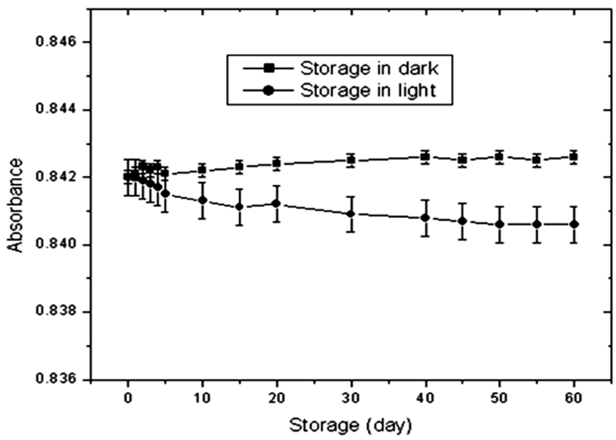

Figure 7. Post-irradiation stability of PVC dyed films in dark and indirect daylight at ambient temperature.

CONCLUSION

The experimental results indicate that the response of these dyed films is linear. The relationship between absorbed dose and relative absorbance at 548 nm in the dose range for up to 150 kGy was established. The response is independent from both dose rate in the studied range and irradiation temperature in the range of up of to 60 °C. Film dosimeters made from PVC dyed with methyl red were found to have a good shelf life for studied period of more than two months in darkness, whereas; they were slightly affected by day light. These results contribute in supplying the industrial irradiation processing and quality control of the absorbed dose as routine dosimeter, in food irradiation and medical materials fields

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Conflict of interest: *Declared None*

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