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Experimental study on Fricke gelatin gel dosimeters

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HIGHLIGHTS

- Optical absorbance study of Fricke gelatin gel dosimeters was performed.
- 80% reduction of dose response for a change in gelatin concentration from 3% to 8% by weight.
- Good repeatability and no dose rate dependence of the gel response.
- Fricke agarose gel dosimeter is more sensitive than Fricke gelatin gel dosimeter.

ABSTRACT

Fricke gel dosimeters obtained by modifications on standard Fricke dosimeter presents some advantages like easy preparation, tissue equivalence, good reproducibility and dose mapping. In this work, dose response characteristics of Fricke gelatin gel dosimeters was investigated and compared with Fricke agarose gel dosimeters in terms of sesitivity. After prepration of three different formulation of Fricke gelatin gel dosimeters and gamma irradiation of the samples, a spectrophotometer was applied to measure the optical absorbance of the samples. Results indicate a linear dose range response of 10 to 30 Gy, as well as increased gelatin concentrations cause the sensitivity of the dosimeter to detereorate with a 80% reduction of dose response for a change in gelatin concentration from 3 to 8 weight percent. Obtained coefficient variation verifies the good repeatability of the gel response. The gel dosimeter has no dose rate dependence. Comparison of the most sensitive Fricke gelatin gel sample with the prepared Fricke agarose gel samples confirm that Fricke agarose dosimeter is more sensitive than Fricke gelatin gel dosimeter.

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1 Introduction

In any applications of ionizing radiation accurate determination of the absorbed dose is of great importance. Standard Fricke solution for radiation dosimetry has been modified with addition of a gelling agent over the years, the dosimeter becomes more sensitive and the radiation doses more stable (Scotti et al., 2022). Fricke gel dosimetiers have been widely studied by many researchers in the past years and various materials have been proposed. In 1989, the influence of gelling agent on the ferrous sulphate dosimetry system was investigated (Olsson et al., 1989). In 1991, the nuclear magnetic resonance longitudinal relaxation rate characteristics of a ferrous sulphate dosimeter immobilized in a gelatin matrix were explored (Hazle et al., 1991). In 1996, diffusion coeffient of Fricke gelatin gel dosimeters was determined by irradiating the lower section of a cylinder of gel which was imaged over time (Rae et al., 1996). In 1997, a model based on ferric ion yield, ferrous and ferric ion relaxivities was presented for the dose dependence of the spin lattice relaxation rate (Audet and Schreiner, 1997). In 2000, a gelatin gel of different composition has been characterised for radiation dosimetry (Bero et al., 2000). In 2004, it was shown the dose response of ferrous xylenol orange gelatin gel dosimeter is relatively insensitive to mixing temperature and additional oxygenation (Healy et al., 2004). In 2007, 270 bloom gelatin was used to modify the conventional Fricke solution. The developed material had good performance to be applied to measurements of spatial distribution of gamma dose using magnetic resonance imaging (GALANTE et al., 2007). In 2008, spectrophotometric measurements of the Fricke gelatin xylenol orange gel dosimeter demonstrated reproducible linear dose response up to 25 Gy (Davies

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Table 1: The concentration of the constituents of the gels investigated in the study.

Gel	Gelatin (% w/w)	Sulphuric acid (mM)	Xylenol orange (mM)	Ferrous ammonium sulphate (mM)
A	3	25	0.165	0.5
B	5	25	0.165	0.5
C	8	25	0.165	0.5
D	-	25	0.165	0.5

and Baldock, 2008). In 2010, the spectrophotometric responses of Fricke gelatin gel dosimeters using 270 bloom gelatin and 300 Bloom gelatin were compared (Cavinato and Campos, 2010). In 2014, three dimensional mapping of the neutron fields through nuclear magnetic relaxometry and magnetic resonance imaging of Fricke gels exposed to neutrons was investigated (Marrale et al., 2014). Also in this year, methodologies to obtain diffusion coefficients associated with the variation of their reagents and stored temperature was surveyed (de Oliveira et al., 2014). In 2015, it was shown that Fricke Xylenol Gel dosimeter (FXG) is tissue equivalent, energy independent and stable in temperature less than 10 °C (El Gohary et al., 2015). In 2016, magnetic resonance measurements of FXG performed at various times after irradiation revealed the slow changes due to the auto oxidation effect (Gambarini et al., 2017). In 2019, a mathematical model implementation for studying the diffusion process of ferric ions in post irradiated Fricke gel dosimeters was presented (Vedelago et al., 2019). In 2021, absorbed dose distributions measured using radiochromic films and Fricke gelatin gel dosimeter layers were compared with dose distributions calculated by using a treatment planning system and Monte Carlo simulations (Pérez et al., 2021).

There are no many suitable dosimeters for irradiation quality control in a dose range of a few to a few tens of Gy that the Fricke gels respond well. This issue led us to investigate the Fricke gelatin gel dosimeters sensitivity and the effective parameters on that, which gelling agent percent is one.

We tried to expand the range of gelling agent percent of Fricke gelatin gel dosimeters reported in literature. In ordert to survey the variation in the formulation of Fricke gelatin gel dosimeters in terms of its gelling agent, three different solutions were prepared. Irradiation of the samples were performed by a Gammacell. Optical absorbance of the samples was readout by a spectrophotometer. Dose response characteristics of Fricke gelatin gel dosimeters was investigated. Coefficient of variation of the dosimeter was estimated. The effect of varying the irradiation dose rate on gel response was surveyed. At last, dose response of Fricke gelatin gel dosimeters compared with the one of Fricke agarose gel dosimeters in terms of sesitivity.

2 Experimental

The FXG components were as follows: gelatin, weight percent was changed from 3% to 5% and 8%, xylenol orange 0.165 mM, sulphuric acid 25 mM, ferrous ammonium sulphate 0.5 mM, obtaining three different solutions: A (3% w/w), B (5% w/w) and C(8% w/w). Table 1 gives information about dosimeter constituents with the concentrations of each element. All the materials were supplied by Sigma-Aldrich company. The preparation procedures generally affect the dosimeter performance, therefore, a defined protocol for manufacturing is needed to be followed consistently. Gelatin was mixed with water to 75% of the dosimeter volume and left for some minutes to absorb. Ultrapure water was used to avoid contamination with other species. Then the mixture was heated at 45 °C and continuously stirred with a magnetic stirrer until the powder completely dissolved and a clear solution was obtained.

The chemicals in water made up the other 25% of the dosimeter volume. After preparing the A, B and C solutions, they were inserted into cuvettes with dimensions of $1\times1\times4$ cm^3 sealed with parafilm and placed in a refrigerator (Fig. 1). All irradiations were performed with a Co-60 source (Gamma cell-220, Nordion, Canada), at 0.9 $Gy.s^{-1}$ of dose rate. The prepared dosimeters were maintained at room temperature during 30 min before irradiation.

The optical properties of the gel in the visible region of light spectrum were investigated using BECKMAN COULTER DU-800 in order to find the best features for measuring the absorbed dose. The spectrophotometer was operated in absorbance mode and changes of optical density was in 1 cm path length. The optical measurements were performed thirty minutes after irradiation.

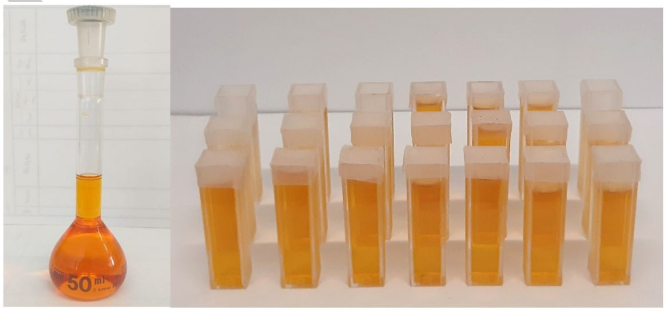

Figure 1: Preparation of the dosimeters.

3 Results and discussion

Figure 2 illustrates the absorption spectra of a set of dosimeters, which were exposed to different gamma radiation doses up to 50 Gy. The optical density values were obtained by scanning the samples over the wavelength range 350 to 650 nm, which spans the visible spectrum. Important features of the optical density spectrum are one broad absorption peak centred around 585 nm, corresponding to Fe^{3+} ions generated by radiation induced Fe^{2+} ions oxidation, with the optical density increasing in proportion to the dose and another broad absorption peak centred around 435 nm, corresponding to initially existed Fe^{2+} ions in the unirradiated gel decreasing with dose increase. The trend of the spectrum was in line with the results published in 2021 (Gallo et al., 2021). Gel responses at wavelengths 585 nm for different gel weight percent are plotted in Fig. 3 which indicates a linear dose range response of 10 to 30 Gy and a saturation effect after 30 Gy start to dominate mainly due to the consumption of dye molecules. The presented data in all dose response curves correspond to the arithmetic mean of three samples for each absorbed dose studied. Error bars (one standard deviation) are smaller than the plot symbols.

The dosimeter sensitivity is expressed in term of the change in the optical density per unit absorbed dose which is equal 0.061 $Gy^{-1}.cm^{-1}$ for 3% gelatin concentration, 0.058 $Gy^{-1}.cm^{-1}$ for 5% gelatin concentration and 0.055 $Gy^{-1}.cm^{-1}$ for 8% gelatin concentration, respectively as reprted in Table 2. The obtained gel sensitivity is in agreement with the previously work reported by Healy et al. (Healy et al., 2004). Preliminary results show that increased gelatin concentrations up to 8% by weight have a deleterious effect on dose response of the gel with a 80% reduction of dose response for a change in gelatin concentration from 3% to 8% by weight.

To survey the uncertainty in the doses calculated from absorbance measurements, eighteen gel samples in groups of three samples were irradiated to five doses. Figure 4 illustrates the coefficient of variation for each dose level. The data indicate that the coefficient variation ranges from about 0.8 at 50 Gy to approximately 1.2 at 10 Gy which verifies the good repeatability of the gel response. Figure 5 shows the absorbance of Fricke gelatin gel dosimeters as a function of the absorbed dose rate. Error bars (one standard deviation) are smaller than the plot symbols. For dose rate reduction, a designed lead shield was used during irradiation process. In that case, dose rate became one third of the conventional value. As can be seen, there is no absorbed dose rate dependence.

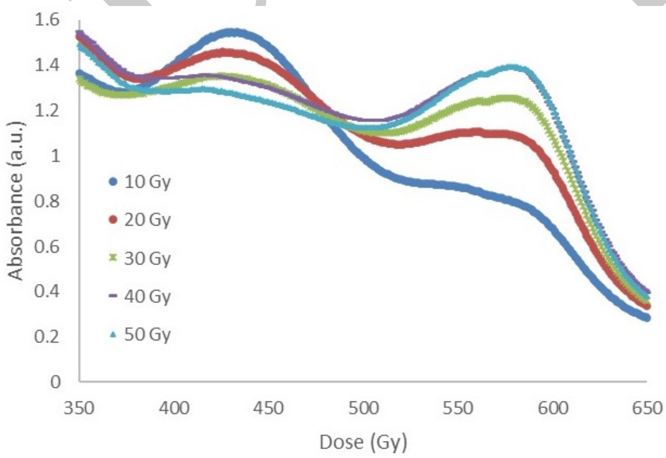

Figure 2: Spectra of the gel dosimeters.

Table 2: Sensitivity of the prepared gel dosimeters.

	Gel A	Gel B	Gel C
Sensitivity ($Gy^{-1}.cm^{-1}$)	0.061	0.058	0.055

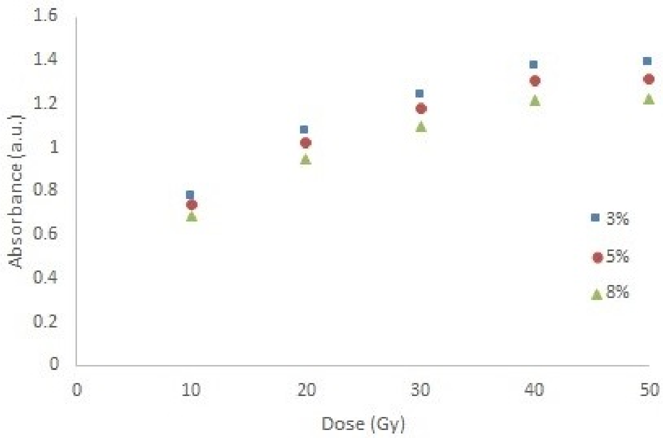

Figure 3: Dose response curves at three different concentrations of gelatin.

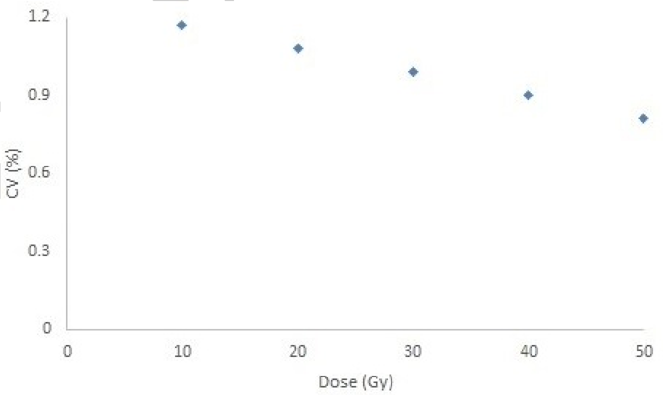

Figure 4: Coefficient of variation of the dosimeter response.

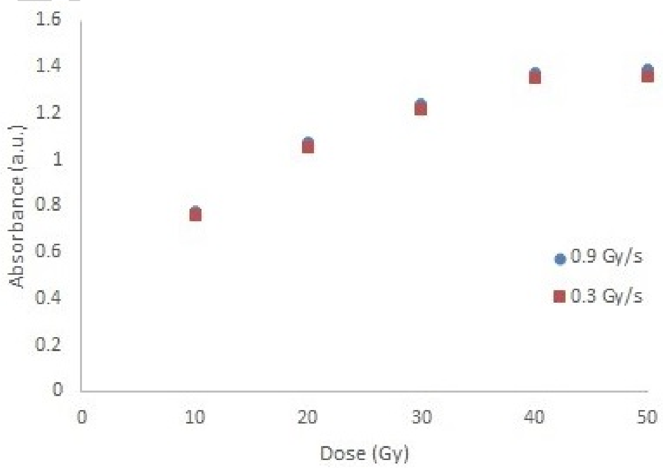

Figure 5: Dose response curves at different dose rates.

In order to compare the sensitivity of 3% precent by weight Fricke gelatin gel dosimeters (the most sensitive one) with the sensitivity of 3% precent by weight Fricke agarose gel dosimeters, samples of the gel were prepared, in accordance with Gel D in Table 1, with the mthod mentioned in (Gambarini et al., 2017). Gel D was similar to gel A, except for replacing gelatin with agarose. After irradiation at the same doses and absorbane measurement at 585 nm of the samples, the dose response curve of the gel was obtained. Figure 6 illustrates the dose response curves of the two gels. Error bars (one standard deviation) are smaller than the plot symbols. The results show the absorbance of the dosimeters prepared with agarose is higher than that of dosimeters made with gelatin. Trend of the two response curves is the same, the increase of the absorbances with increasing the dose, but sensitivity of the Fricke agarose gel is about 0.065 $Gy^{-1}.cm^{-1}$ which is about 30% more than the sensitivity of the Fricke gelatin gel dosimeter.

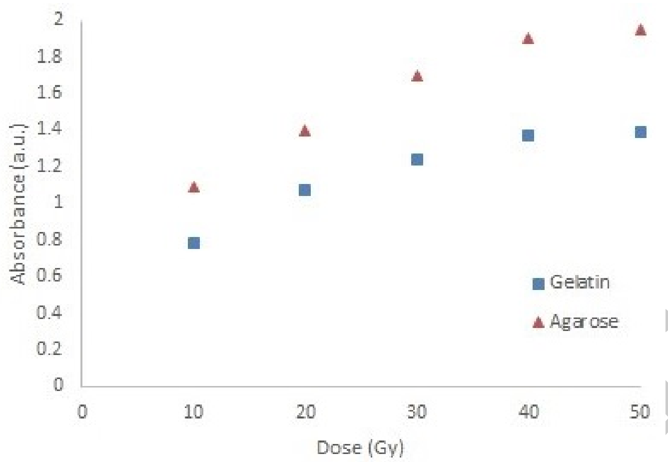

Figure 6: Gelatin dose response curve compared with agarose.

4 Conclusions

Radiation measurement with FXG dosimeters is a sensitive technique that can be used in medical applications like radiotherapy to obtain a special dose distribution. Since the dosimeter is prepared in solution form and is tissue equivalent, it can be made in any format to simulate organs of the human body. The Fricke gels made of gelatin and agarose seem to be suitable for constructing phantoms for dose distributions measurement, which will be surveyed by the authors in the next work. Although agarose gives a better sensitivity than gelatin, it is more complicated to mix the agarose gel when large volumes are required.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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