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Fe^{+3} DIFFUSION COEFFICIENT IN FRICKE XYLENOL GEL THROUGH SHIELDING HALF OF A 6 MV PHOTON BEAM FIELD SIZE

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ABSTRACT

Diffusion of ions can be observed in a solution or gel when a difference occurs in their concentrations. For dosimetric gels, the diffusion can interfere on measurements of absorbed dose delivered to the patient in a radiotherapic treatment, when the time interval for measurements pos-irradiation is considered long. In the present work, a pos-irradiation Fricke Xylenol Gel (FXG) spatial dose distribution was obtained for several time intervals and the diffusion coefficient was inferred following a literature theoretical methodology. Using FXG samples, whose $[Fe^{2+}]$ are oxidated to $[Fe^{+3}]$ when irradiated, the diffusion coefficient for the last ion was obtained in order that one can have the real spatial dose distribution right after the irradiation and this was done using half shielded 6 MV photons field size. Each sample, for each time interval selected (from 2.8 up to 28.6 hours) was analyzed in function of their optical absorbance. From Fick's law and from an error equation, the diffusion coefficient was inferred, which can be used to correct the absorbance positions promptly after irradiation. The diffusion coefficient found for the FXG dosimeter, has the value of 0.452 mm^2/h, that is between the interval of 0.3 up to 2.0 mm^2/h, predicted for gel type dosimeters.

1. INTRODUCTION

In radiotherapy the main focus is to assure that the prescribed dose is exactly the one to be delivered to the patient, which can be done through accurate dosimeters that present linear dependence and high sensitivity in the absorbed dose range to be used, effective atomic number and density close to those of soft tissue. The Fricke Xylenol Gel (FXG) dosimeter has been used for radiotherapic purposes, because of its ample linear dependence with the absorbed dose and atomic number and density of 7.75 and 1.05 g/cm^3, respectively [1-6]. This dosimeter has a colorant (xylenol orange) and Fe^{2+} in its composition that, when irradiated, are oxidized to Fe^{3+} forming the xylenol-ferric complex, with the concentration proportional to the absorbed dose.

The FXG composition differentiates from the standard one, proposed by Fricke and Morse [7], due to the addition of swine skin gelatin and xylenol orange, that improved its stability and sensitivity. New modifications of the FXG, as adding benzoic acid, can make it suitable also for measurements in the diagnostic energy and dose range [8].

The FXG presents adequade properties that make it suitable for radiotherapic measurements, but the absorbed dose readings can be compromised when they are done after long periods of time post-irradiation, because of the ions spatial diffusion. Therefore this time must be controlled what can be done through the diffusion coefficient correction to the absorbance values obtained.

Ions diffusion occurs because there is a difference in their concentration in a solution or gel, leading to a concentration gradient as a function of space and time. The diffusion coefficient was initially investigated, using the nuclear magnetic resonance technique, and more recently using the optic density techniques [9]. An interesting methodology used to obtain the diffusion coefficient was used by Kron *et al* [10] with the NMR technique, that using two gel samples (side by side) doped with Fe^{2+} and Fe^{3+} respectively, with the last one simulating an irradiated gel, studied the Fe^{3+} diffusion through the ions relaxation time. In this methodology the difference between the two regions with different concentrations can be presented by a curve, an error function, whose derivative at the inflection point gives a function that can be fitted by a theoretical Gaussian, solution for the Fick equation for space and time diffusion, as occurs with the Fe^{3+} in the gel matrix. Matching these two Gaussians, the diffusion coefficient can be obtained.

In the present work, although the same theoretical tool was used to obtain the diffusion coefficient for the FXG, the gel was not doped with different ion concentrations, this was achived shielding half of the ionization beam size and the spectrophotometry technique was used to obtain the behaviors of the absorbances for the two different regions (irradiated and non irradiated). The FXG was inserted in cuvettes, irradiated with 6 MV photons beam and measured with a spectrophotometer at 585 nm, related to the highest absorbance peak. With this new set up of half beam size irradiation and using the optical spectrophotometry technique, the diffusion coefficient was obtained for this particular gel.

2. MATERIALS AND METHODS

The FXG used is composed of swine skin gelatin (300 Bloom), 260 μl sulfuric acid, 0.5 mM ferrous ammonium sulphate, 0.01 mM xylenol orange and Milli-Q water. This solution filled three acrylic cuvettes (1.25 x 1.25 x 4.50 cm^3) that were positioned side by side and irradiated with a 6 MV photon beam (Siemens/Mevatron/6MD) using a 10 x 10 cm^2 field size, 100 cm source-surface distance (SSD) at the build-up depth of 1.5 cm. The three samples were symmetrically centralized with the beam axis and half of the field was shielded to allow that the already referred method, to obtain the diffusion coefficient, could be applied [10], Fig. 1 a). The irradiated samples permitted the absorbance readings along their middle line for each cuvette, that were averaged *versus* spatial variation for selected time intervals as in Fig. 1 b).

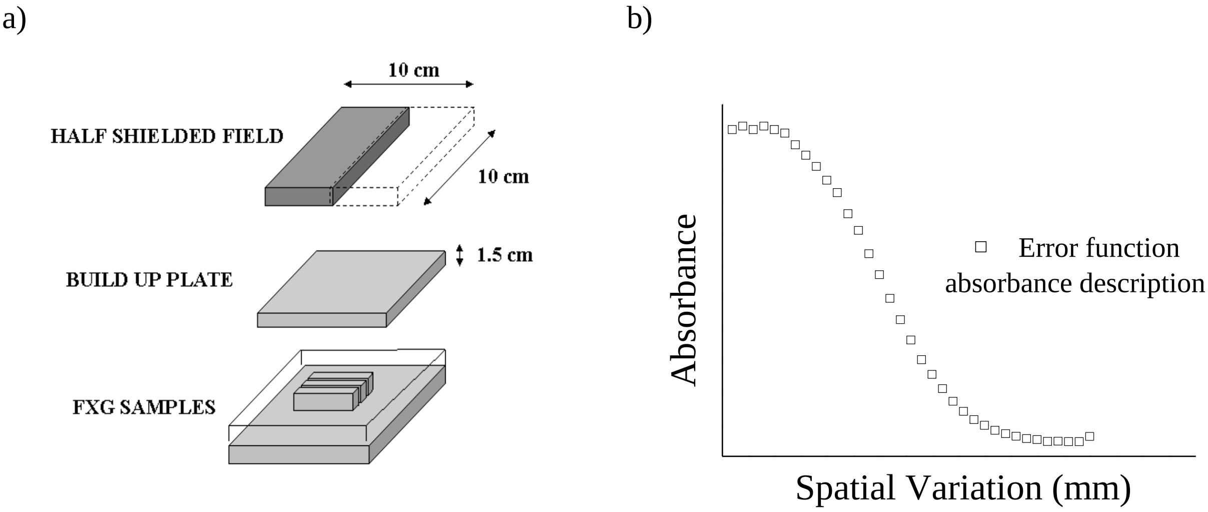

Figure 1. a) Experimental set up for FXG samples irradiation and b) Expected curve for the absorbance behavior *versus* spatial variation.

Also, to avoid temperature dependence in the results, the samples were prepared and measured in room temperature. According to the literature [10] the absorbance *versus* spatial variation can be given through an error function, as follow:

$$A = A_B + \frac{1}{2}(A_S - A_B)\cdot\left[1 - \frac{x}{(x^2 + n)^{1/2}}\right] \quad (1)$$

Where A_B and A_S are the absorbance readings at points in the base and saturated regions of the curve; x is the distance initial reading from the inflection point and n is the curvature parameter after a certain time interval, related to the spatial variation.

From equation (1), the curvature parameter n can be inferred for each specific curve, related for different pos-irradiation times. Once the diffusion of the Fe^{3+} ions can be also related to the Fick equation, because of space and time variations, the derivative of the equation (1), at the inflection point, gives a function that can be approximated to a Gaussian. The belt (FWMH) of this Gaussian can be linked to the diffusion coefficient (from the Fick's law) by the relation

$$\sigma^2(t) = 2Dt \tag{2}$$

Matching the FWMH from the two functions (measured and theoretical) one can obtain the curvature parameter *n*, for each time pos irradiation, and the diffusion coefficient can be inferred from the slope of the curve *n versus* t, derived from

$$D = 0.127\frac{n}{t} \tag{3}$$

3. RESULTS AND DISCUSSION

Absorbance readings were averaged from three half-shielded FXG samples for different pos-irradiation time intervals, as shown in Fig. (2).

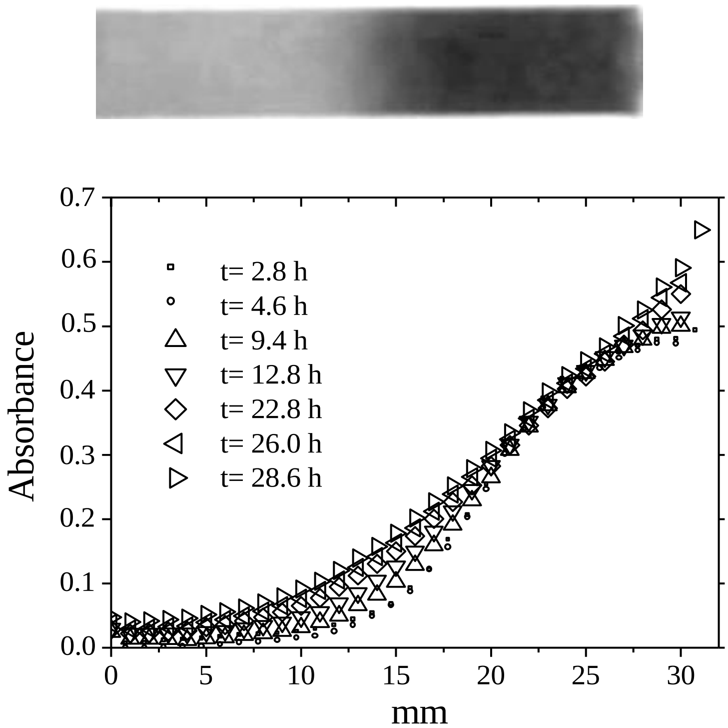

Figure 2. Absorbance *versus* distance for several time intervals, pos-irradiation.

From these curves, the curvature parameter n could be inferred for its respective time intervals using equation (1), from the two FWMH matching derived from equation (3) whose behavior is presented in Figure (3). The linear function allows to obtain the angular coefficient, needed to replace the n/t ratio in equation (3). From this procedure, the diffusion coefficient, D, was found as 0.452 mm^2/h, with a correlation coefficient of 0.985.

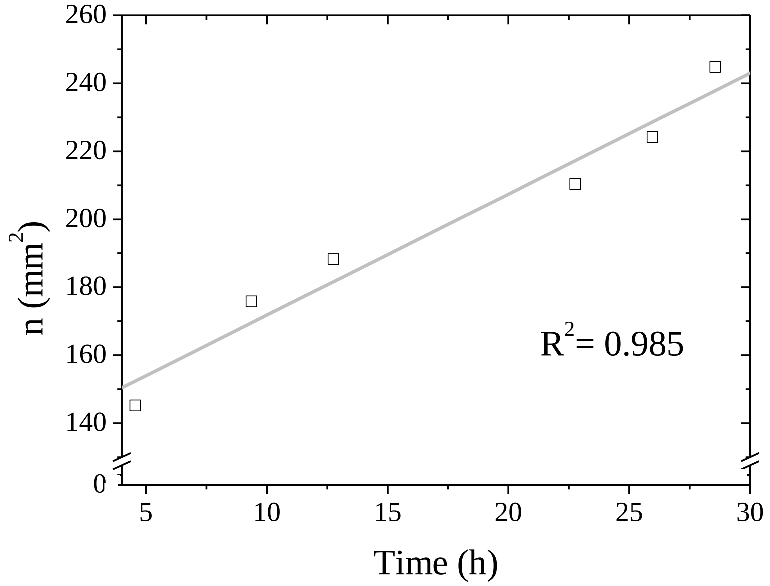

Figure 3. Curvature parameter n related for each time pos-irradiation to find the angular coefficient and consequently the diffusion coefficient.

4. CONCLUSIONS

Absorbance measurements, done along the FXG samples, were fitted by an adequate error function, to allow the use of the presented method and infer the diffusion coefficient for the FXG gel. From the curvature parameter n *versus* time interval pos-irradiation, the angular coefficient could be inferred, that once substituted in equation (3) provided the diffusion coefficient of 0.452 mm^2/h, which is not further from the values suggested by the literature for gel diffusion coefficient in chemical dosimeters (0.3 up to 2.0 mm^2/h) [10].

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