Effective Atomic Number and Electron Density Determination for Fricke Gel Dosimeters Using Different Methods

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Abstract

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Keywords: Effective atomic number, electron density, fricke gel dosimeter, water equivalence

MATERIALS AND METHODS

The chemical composition of four Fricke gel dosimeters studied is available for Ferrous Agarose Xylenol (FAX) gel,[8] Ferrous Xylenol Gelatin (FXG) gel,[9] FXG Glycin (FXGG) gel[10] and Ferrous Xylenol.

Poly(vinyl alcohol) Glutaraldehyde (FXPVA-GTA) gel.[11] Table 1 reports the corresponding elemental compositions, calculated as fraction by weight for all Fricke gel dosimeters used in this work.

Mass attenuation coefficient

The mass attenuation coefficients for the Fricke gel dosimeters have been calculated using WinXcom computer program.[12]

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In this work, the effective atomic number (Z_{eff}) was evaluated by three methods described below.

• Auto-Z_{eff} computer program evaluated the Z_{eff} through the smooth correlation between atomic cross section and

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atomic number. The $Z_{\text{eff}}$ of each material is calculated at discrete energy levels over the energy range of 10 keV–1 GeV.

- **Direct method**, by this way the effective atomic number of the Fricke gel dosimeters can be obtained using the following formula:

$$Z_{\text{eff}} = \sum f_i A_i \frac{\mu_i}{\rho_i} \left( \frac{Z_i}{A_i} \right) \left( \frac{\mu_i}{\rho_i} \right),$$

where $f_i$ is the molar fraction in the mixture/compound, $\mu/\rho$ is the mass attenuation coefficient calculated with WinXcom, $A_i$ is the mass number and $Z_i$ is the atomic number.

- **Power law method** dates back to 1930s, it allows us to calculate the effective atomic number for mixture by means of the next equation:

$$Z_{\text{eff}} = \left[ \sum f_i (Z/A) \right]^{1/\alpha}$$

With the mass numbers, $A_i$, the atomic number, $Z_i$, and the percentage mass composition of the element, $i$, to the sample $f_i$ and $\alpha$ as an empirical number which is taken to be 2.94.

The electron density of the Fricke gels has been calculated according to the succeeding expression:

$$N_e = Z_{\text{eff}} N_A / \langle A \rangle$$

where $\langle A \rangle$ is the average atomic mass of the gels, and $N_A$ is the Avogadro’s number.

## Results

### Mass attenuation coefficient

Figure 1 shows the variation of the mass attenuation coefficient, $\mu/\rho$, calculated at the photon energies between 0.1 MeV and 100 MeV for four Fricke gel dosimeters and water.

### Effective atomic number and electron density

The calculated values of $Z_{\text{eff}}$ and $N_e$ for different Fricke gels dosimeters examined and water are presented in Figures 2 and 3, respectively.

The effective atomic number and electron density of the Fricke gels dosimeters relative to water were also calculated to evaluate the water equivalence of each of them. The results obtained are shown in Table 2.

## Discussion

From the data illustrated in Figure 1, it can be seen that the mass attenuation coefficient is decreasing with the increasing photon energies.

In general, as shown in Figures 2 and 3, $Z_{\text{eff}}$ and $N_e$ behavior with photon energy for all dosimeters studied are similar. The $Z_{\text{eff}}$ and $N_e$ data, calculated by Auto-$Z_{\text{eff}}$ and direct methods shows the variation of up to 2.5% in the energy region 0.1 MeV ≤ $E$ ≤ 4 MeV, 9% and 23% in the energy regions 5 MeV ≤ $E$ ≤ 10 MeV and 11 MeV ≤ $E$ ≤ 100 MeV, respectively.

A good agreement is achieved in comparison in the region 0.1 MeV ≤ $E$ ≤ 10 MeV this is the energy interval of interest in X-rays external radiation therapy.

The effective atomic numbers calculated by power method are 7.45, 7.42, 7.42, 7.38, and 7.44 for FAX gel, FXG gel, FXGG gel, FXPVA-GTA gel, and water, respectively. The effective electron density calculated by power method is 3.13, 3.12, 3.12, 3.14, and 3.13 for FAX gel, FXG gel, FXGG gel, FXPVA-GTA gel, and water, respectively. It was found that the calculated $Z_{\text{eff}}$ and $N_e$ using Auto $Z_{\text{eff}}$ and direct methods are lower than what were calculated using power law methods. This discrepancy can be assigned to the energy independence of the Mayneord formula.

From the data shown in Table 2, the percentage difference of up to 0.3%, 0.9%, and 1.5% for FAX, FXPVA-GTA, FXG, and FXGG gels, respectively, was obtained when comparing data for $Z_{\text{eff}}$ of Fricke gel dosimeters to that of the water. Discrepancies of up to 0.2%, 2.25%, and 2.26% for FAX,
FXPV A-GTA, FXG, and FXGG gels, respectively, were observed when comparing data for Ne of Fricke gel dosimeters to that of the water.

**Conclusion**

In this study, Z_{eff} and Ne of water and Fricke gel dosimeters were calculated for photon using theoretical methods. The direct and Auto-Z_{eff} methods show a very good agreement in the effective atomic numbers in energy region 0.1–10 MeV. Electron density is closely related to the effective atomic number and has the same quantitative energy dependence as Z_{eff}. It was found that the calculated effective atomic number and electron density of the Fricke gel dosimeters using the direct and Auto Z_{eff} methods, were lower than that calculated using the power law method. This mismatch can be attributed to the energy independence of the method. As such, the differences in effective atomic number (0.3%–1.5%) and Ne (0.2%–2.26) between water and Fricke gels are small, consideration of the mean disparity over energy range 0.1–10 MeV shows, widely, FAX gel to be the most water equivalent gel.

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**Conflicts of interest**

There are no conflicts of interest.

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**Table 2: \( \langle Z_{eff}\rangle \) and \( \langle N_e\rangle \) calculated for different Fricke gel dosimeter formulations in terms of values for water in the energy range 0.1-10 MeV**

| Quantity          | FAX    | FXG    | FXGG   | FXPV A-GTA |
|-------------------|--------|--------|--------|------------|
| \( \langle Z_{eff}\rangle/\langle Z_{eff}\rangle_{water} \) | 1.000a | 1.012a | 1.012a | 1.003a      |
|                   | 1.003b | 1.015b | 1.015b | 1.006b      |
|                   | 1.001c | 0.997c | 0.997c | 0.991c      |
|                   | 1.005d |        |        |             |
| \( \langle N_e\rangle/\langle N_e\rangle_{water} \) | 1.002a | 1.011a | 1.011a | 1.014a      |
|                   | 1.001b | 1.026b | 1.026b | 1.025b      |
|                   | 1.000c | 0.996c | 0.996c | 1.003c      |

\( \langle Z_{eff}\rangle \) and \( \langle N_e\rangle \) are the average effective atomic number and electron density, respectively. FAX: Ferrous Agarose Xylenol, FXG: Ferrous Xylenol Gelatin, FXGG: Ferrous Xylenol Gelatin Glycin, FXPV A-GTA: Ferrous Xylenol Poly(vinyl alcohol) Glutaraldehyde.
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