[1]Master Student, and
[2]Assistant Professor of Physics, Department of Physics, Yazd University, Yazd, Iran
[3]Associate Professor of Medical Physics, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

Evaluation of Ferrous-Agarose-Xylenol Gel Properties in Radiation Dosimetry

Dehghan M.[1], Mokhtari H.[2], Bouzarjomehri F.[3]*

Abstract

Background: Over recent decades, modern protocols of external beam radiotherapy and radiation techniques such as intensity-modulated radiotherapy (IMRT) have been developed. These methods are extremely sensitive to errors in treatment delivery, so that it is essential to apply a high resolution 3D dosimetry system that has high sensitivity and is capable of measuring and verifying the complex delivery. The ferrous-agarose-xylenol orange (FAX) gels the material properties of which are changed when irradiated have been suggested for such use.

Objective: In this study a FAX gel dosimeter was examined for dose linearity for photon and electron beams.

Methods: FAX gel was prepared using 0.4 mM (FAS), Fe $(NH_4)_2(SO_4)_2 \cdot 6H_2O$ of analytical grade, 25 mM H_2SO_4 98%, 0.2 mM (XO) xylenol orange-sodium salt, 1% by weight of agarose gel powder and the remaining mass of the solution being highly pure deionized water. FAX gels were exposed to doses up to 20 Gy using 9 MV photon and 6 MeV electron beams by Neptun LINAC. Some general characteristics of FAX such as optical absorbance-dose relationship, sensitivity and reproducibility were analyzed.

Results: Although the measurements showed linearity in optical absorbance-dose relationship up to 18 Gy for photons and electrons, oxidation processes continued post-irradiation and storage conditions such as temperature and light affected the response of this dosimeter. The best composition by high sensitivity and stability of dosimeter was found to be 0.4 mM FAS, 0.2 mM XO and 25 mM H_2SO_4.

Conclusion: The above-mentioned FAX gel and UV-visible spectrophotometry as a reader are a sensitive and cheap dosimetry system for radiotherapy.

Keywords
Radiation dosimetry; FAX gel; Spectrophotometry; Sensitivity; Reproducibility

Introduction

The need for reliable, three-dimensional dosimetry in modern radiotherapy has been extensively reported in conjunction with reports of developments in gel-based dosimetry [1]. The Frick-agarose-xylenol (FAX) gels can be modified to be almost equivalent to soft tissue in dosimetry in terms of factors such as accuracy, sensitivity, the time needed for dosimetry, three-dimensional capabilities, energy independence, dose rate independence, and costs [2]. In FAX gel, the metal ion indicator, xylenol orange (XO), binds to Fe^{3+} forming a visible colored complex ($XO\text{-}Fe^{3+}$) that can be measured spectrophotometrically. By adding the chelating agent, XO to ferrous sulfate agarose gel dosimeter the sensitivity for this dosimeter has significantly been improved for the absorbed doses region in radiotherapy [3-5]. The FAX

*Corresponding author:
F. Bouzarjomehri,
Tel: +98-351-725-1171
E-mail: bouzarj_44@ssu.ac.ir

dosimeter is comprised of ferrous ammonium sulfate (FAS), XO, sulfuric acid (SA), distilled water and agarose. The agarose is responsible for increasing the ferric ion yield whilst the XO sensitizes the measurement of ferric ion yield [6]. While some studies used gelatin as the gelling agent [7-9], agarose has the advantage of melting at a higher temperature meaning it is more stable. Fricke gel dosimeter is easy to prepare and less expensive compared with polymer gels, but unlike Fricke gel, the radiation products of polymer gel do not diffuse between irradiation and scanning times [10,11]. However, with adding XO the rate of diffusion of ferric ions is decreased [12]. In this study a FAX gel dosimeter was manufactured by a recipe provided by Tarte, *et al* [13], and examined for dose linearity for photon and electron beams.

Materials and Methods

Gel Preparation

Gel samples were prepared using 0.4 mM ferrous ammonium sulfate hexahydrate (FAS), $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ of analytical grade, 25 mM sulfuric acid (H_2SO_4) 98%, 0.2 mM xylenol orange-sodium salt, 1% by weight of agarose gel powder and the remaining mass of the solution being highly pure deionized water, all from Merck Company [6].

All glassware was rinsed with deionized water and was completely dried in an oven. The gels were prepared by heating the mixture of agarose gel powder and deionized water to approximately 85 °C and continuously stirred with a magnetic stirrer until the powder was completely dissolved to produce a clear solution. Then sulfuric acid, ferrous ammonium sulphate and xylenol orange dye solution of equal volumes were added at 60 °C. Different concentrations of ingredients were prepared, keeping concentrations of all other ingredients constant to find a stable and more sensitive gel. The color of solution should be clear bright orange. The whole process was performed in

Figure 1: FAX gel before (orange) and after irradiation (purple) by 9 MV photon beam

air and in day light. The gel solution, till became warm, was inserted in separate vials. Vials used in this study were made from Pyrex glass, 100-mm long and had an outer diameter of 13 mm. The gels were stored in light-proof containers in a refrigerator for 24 hours at 6 °C before use. The gels were brought to room temperature one to two hours before irradiation.

Irradiation of samples

In each experiment, three gel samples were exposed to irradiation simultaneously. In this study two radiation sources were used—pho-

Figure 2: FAX gels irradiated with 6 MeV electrons. With decrease in absorbed dose from top to bottom of the cuvettes, the color intensity of gels becomes lighter.

ton and electron beams. Irradiation was performed using a linear accelerator (Neptun, Poland), delivering a 9 MV photon beam with dose rate of 300 MU/min. All of the beams were calibrated according to the TRS 398 protocol. Samples were irradiated with a 10×10 cm^2 field size at 100 cm source-to-surface distance (SSD), under which 100 monitor units (MU) was equivalent to 100 cGy. Gel samples were irradiated at 0 (control), 3, 6, 9, 12, 15, 18 and 21 Gy. Upon irradiation, the color of gel changed from orange to purple.

For electron beam irradiation, the energy of 6 MeV with 100 cm SSD was selected. Irradiation was performed in a field size of 15×15 cm^2.

All dose calibrations by ionization chambers were done with sufficient backscatter. The atmosphere temperature and pressure during both irradiation and absorbance measurements were recorded.

Optical measurements

The optical analyses were performed with a UV-Vis spectrophotometer (Spectronic 2OD) at wavelength of 540 nm, where the FAX spectrum has highest absorbance peak. The effect of varying the concentration of gel ingredients was investigated to figure out a more sensitive dosimeter with the reproducible linear dose response. The changes in optical absorbance before and after irradiation were recorded. All samples were read an hour before and one hour after irradiation. The effect of light and oxygen was analyzed.

Results

Figure 1 shows the cuvettes containing FAX gel before and after irradiation to a maximum dose of 21 Gy by 9 MV photon beams. The irradiated gel is clearly purple against the unirradiated gels with orange color. Figure 2 shows gels irradiated to a dose of 21 Gy with 6 MeV electrons. The penetration depth of electrons is apparent in Figure 2. As the dose increased from bottom to top, the color intensity of gels

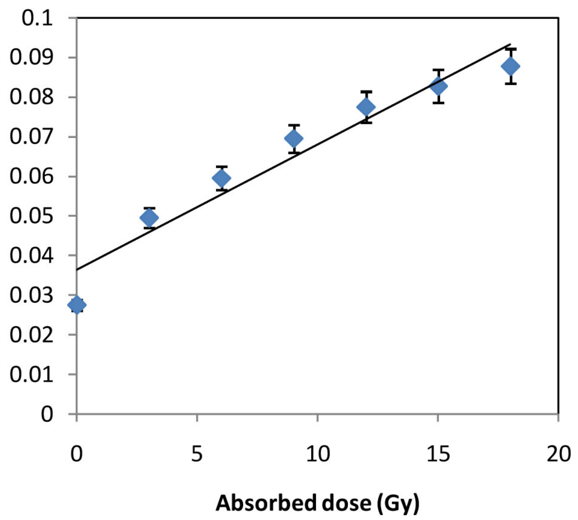

Figure 3: Change in optical absorbance in irradiated FAX gel *vs*. absorbed dose for 9 MV photon

developed. The changes in optical absorbance before and after radiation were measured both for photon and electron beams. The changes were plotted against the absorbed doses. The optical absorbance changes for samples irradiated with photons are shown in Figure 3. FAX gel had a linear dose response up to 18 Gy (r=0.935).

Figure 4 shows the optical absorbance changes plotted against doses given to irradiated samples with 6 MeV electron beams. The FAX gel had a linear dose response between 3

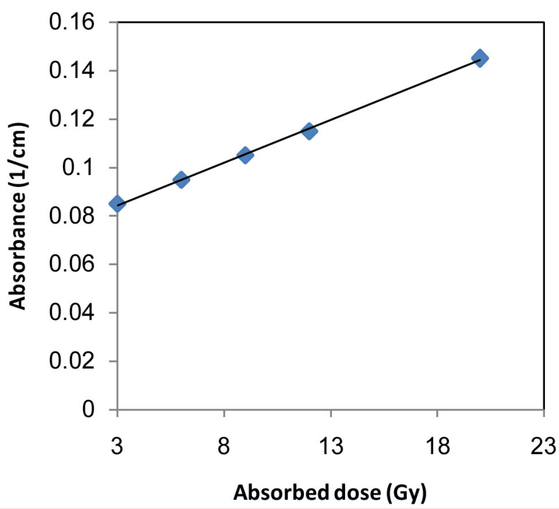

Figure 4: Fax gel dose response for 3 to 20 Gy irradiation by 6 MeV electron beam

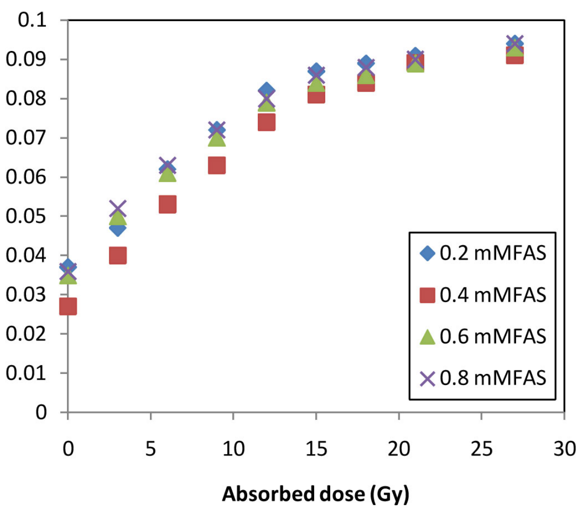

Figure 5: Optical absorbance change as a function of dose for FAX gel with different concentrations of FAS

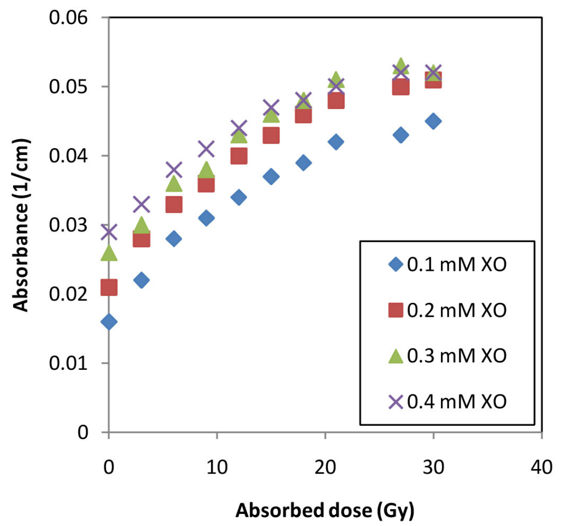

Figure 6: Optical absorbance changes as a function of dose for FAX gel with various XO concentrations

and 21 Gy doses (r=0.998).

Figure 5 depicts the dose response of FAX dosimeter plotted for various concentrations of FAS while concentrations of all other gel ingredients were kept constant at 0.2 mM XO, 25 mM H_2SO_4 and 1% by weight agarose. Table 1 shows the optical absorbance dose sensitivity and correlation coefficients for four different FAS concentrations. FAX gel with 0.4 mM FAS had a higher sensitivity compared with those with 0.2, 0.6 or 0.8 mM FAS. The correlation coefficient of 0.95 for 0.4 mM FAS was higher than those for other concentrations.

The effect of XO concentration on the dose sensitivity is shown in Figure 6. Data for the sensitivity and correlation coefficients of gels with 0.4 mM FAS, 25 mM H_2SO_4 and 1% by weight agarose with various concentrations of XO are presented in Table 2.

The coefficient of variation (CV) of changes in optical absorbance for three samples irradiated simultaneously for each dose was calculated and plotted against the dose (Fig 7).

Discussion

To the best of our knowledge, no document has so far been published on FAX gel dosimeter irradiated by 9 MV photon and 6 MeV electron beams. Leong, *et al*, used 6 and 10 MV photon beams and 9, 12, and 15 MeV electron beams [6]. Appleby, *et al*, used ^{137}Cs gamma rays and 15 MeV electrons [2]. They found that FAX gel had a linear optical absorbance-dose relationship from 0.2 to 10 Gy with a correlation coefficient of 0.998. In our study, the spectrophotometric response had a linear behavior between 3 and 12 Gy with cor-

Table 1: Optical absorbance-dose sensitivity and correlation coefficients for various concentrations of FAS

FAS concentration (mM)	Absorbance-dose sensitivity (1/(cm Gy))	Correlation coefficient
0.2	0.00217	0.930
0.4	0.00245	0.950
0.6	0.0021	0.940
0.8	0.00208	0.934

Table 2: Optical absorbance-dose sensitivity and correlation coefficients for various concentrations of XO

XO concentration (mM)	Absorbance-dose sensitivity [1/(cm Gy)]	Correlation coefficient
0.1	0.000909	0.958
0.2	0.000958	0.96
0.3	0.000905	0.957
0.4	0.000763	0.95

relation coefficient of 0.997 and between 12 and 18 Gy (r=0.999) for photon beams, which are compatible with previously reported data. For the 6 MeV electron beam, the dose range of 3 to 21 Gy had its best linear fit (r=0.998) and a sensitivity of 0.073 1/(cm Gy). These findings are consistent with the data reported by Leong, *et al* [6]. Few researchers worked on the sensitivity of FGX gel dosimeter [5,14]. We could find only one report on the sensitivity of FAX gel with various concentrations of FAS and XO [2]. FAX sensitivity increased with increase in FAS concentration up to 0.4 mM after which the sensitivity decreased. The observed lower sensitivity for low ferrous ion concentration might be due to free radicals and excited molecules, resulting from radiolysis of water in the gel, recombining before they initiate the ferrous to ferric reaction. Beyond the optimum concentration of 0.4 mM of FAS, higher concentrations of ferrous ions caused the response to fall off slowly that might reflect interference of excess ferrous ions on the complex that the ferric ion makes with the ion indicator. For various XO concentrations also the sensitivity increased with increase in XO concentration up to 0.2 mM after which the sensitivity decreased. Our data were completely compatible with those of Appleby's, *et al*, and Davies's, *et al* [2,5]. However, the correlation coefficients were not changed significantly with increase in XO concentration. We found that the CV for doses <10 Gy was as high as 2.3%; for doses ≥10 Gy it was 1.4%. It can be concluded that FAX gel can be irradiated to doses above 3 Gy with uncertainty kept lower than 2.3%. Therefore, a FAX gel with 0.4 mM FAS, 0.2 mM XO and 25 mM sulfuric acid has the maximum reproducibility and sensitivity. This gel with UV-visible spectrophotometry as a reader is a sensitive and cheap dosimetry system for radiotherapy.

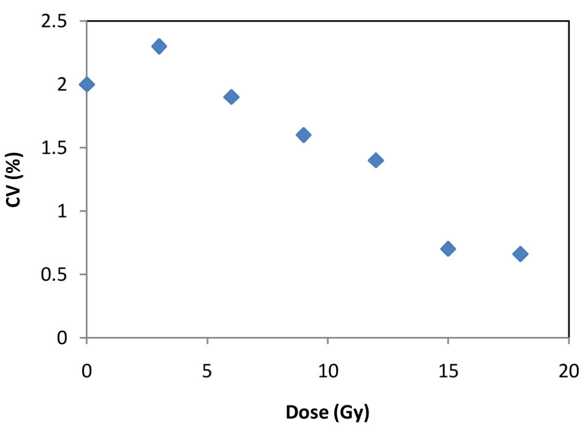

Figure 7: Reproducibility of FAX gel absorbance readings shown as coefficient of variance (CV) against dose for 9 MV photon

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References

1. van Doom T, Bhat M, Rutten TP, *et al.* A fast, high spatial resolution optical tomographic scanner for measurement of absorption in gel dosimetry. *Australasian Physical Engineering Sciences in Medicine* 2005;**28**:76-85.
2. Appleby A, Leghrouz A. Imaging of radiation dose by visible color development in ferrous-agarose-

xylenol orange gels. *Med Phys* 1991;**18:**309-12.

3. Healy BJ, Zahmatkesh MH, Nitschke KN, Baldock C. Effects of saccharide additives on response of ferrous-agarose-xylenol orange radiotherapy gel dosimeters. *Med Phys* 2003;**30:**2282-91.
4. Hazle JD, Hefner L, Nyerick CE, *et al*. Dose-response characteristics of a ferrous-sulphate-doped gelatin system for determining radiation absorbed dose distributions by magnetic resonance imaging (Fe MRI). *Phys Med Biol* 1991;**36:**1117-25.
5. Davies JB, Baldock C. Sensitivity and stability of the Fricke-gelatin-xylenol orange gel dosimeter. *Rad Phys Chem* 2008;**77:**690-6.
6. Leong LH, Kandaiya S, Seng NB. Characterisation of a Ferrous Agarose Xylenol (FAX) gel for radiotherapy dose measurement. *Australasian Physical Engineering Sciences in Medicine* 2007;**30:**135-40.
7. de Oliveira Lucas N, Carmen Sandra Guzm´an Calcina, Fernanda Cavalcante, *et al*. 6 MV Wedge Photon Beam Profiles with the Fricke Xylenol Gel Dosimeter. *Brazil J Physics* 2009;**39:**615-8.
8. Olding T, Salomons G, Darko J, *et al*. A Practical Use for FXG Gel Dosimetry. *J Phys: Conference Series* 2010;**250:**012003 doi:10.1088/1742-6596/250/1/012003.
9. Bero MA. Dosimetric properties of a radiochromic gel detector for diagnostic X-rays. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 2007;**580:**186-9.
10. De Deene Y, Venning A, Hurley C, *et al*. Dose-response stability and integrity of the dose distribution of various polymer gel dosimeters. *Phys Med Biol* 2002;**47:**2459-70.
11. Fong PM, Keil DC, Does MD, Gore JC. Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere. *Phys Med Biol* 2001;**46:**3105-13.
12. Baldock C, Harris PJ, Piercy AR, Healy B. Experimental determination of the diffusion coefficient in two-dimensions in ferrous sulphate gels using the finite element method. *Aust Phys Eng Sci Med* 2001;**24:**19-30.
13. Tarte BJ, Jardine PA, van Doorn T. Laser-scanned agarose gel sections for radiation field mapping. *Int J Radiat Oncol Biol Phys* 1996;**36:**175-9.
14. Caldeira AM, Neto AM, Bento AC, *et al.* Behavior of oxidation in the radioc hromic gel dosimeter through photoacoustic technique measurements. *Appl Radiat Isot* 2007;**65:**605-9.