Effects of ambient temperature on the FXG radiochromic gels used for 3-D dosimetry

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Abstract. Environmental effects on the optical properties of a sensitive radiochromic gel dosimeter; in particular storage, irradiation and measurements temperature were studied. Knowledge of light temperature and other ambient effects help to optimise working conditions and minimize errors. A ferrous-sulphate dosemeter with xylenol orange ion indicator incorporated in a gelatin gel matrix (FXG) was prepared under normal working conditions, and the samples were then kept in closed storage area at different temperature ranging from 5 °C up to the gel melting temperature about 35 °C. The samples optical absorbance was then measured quantitatively using double beam spectrophotometry. There is a small and steady increase in the absorbance \(0.3 \times 10^{-3}/°C\) with increasing temperature until about 30 °C when we observe a big jump in the gel absorbance. Finally, additional important behaviour of FXG material was noticed, that is the changes occurred under the influence of rising temperature are reversible which is different from the permanent radiation caused changes.

1. Introduction

The classic Fricke aqueous solution is usually read out by spectrophotometry, exploiting the characteristic absorption bands of ferric ions centred at 224 and 304nm in the ultra-violet. In the gel form of the Fricke, strong absorption in the UV hinders the use of these wavelengths for thicker samples. In order to achieve a more sensitive Fricke solution, benzoic acid and xylenol orange metal ion indicator was added [1]. This resulted in an absorption band located in the visible region. When xylenol orange (XO) was incorporated into agarose gel for 2-D imaging an absorption peak at 550nm enabled it to be used for larger samples [2]. This radiochromic gel was taken as the starting point for the following developments [3]. FXG radiochromic dosimetry system can be described as a variant of the well-known ferrous sulphate chemical system, famous as the ‘Fricke dosemeter’ and therefore it possesses similar general properties. Besides being tissue equivalent, FXG has sufficient sensitivity, adequate reproducibility and stability for both pre- and post- irradiation [4]. Hence, it satisfies most of the requirements for a dosemeter to be a useful candidate for 3-D dosimetry. Good understanding of the FXG system’s behaviour under different ambient conditions as well as its most important dosimetric attributes is essential.

2. FXG radiochromic gel

Having experimented with both agarose and gelatin gels the latter turned out to have several practical advantages. It was also found that the benzoic acid played no useful role since the high concentration of organic gelatin also served to improve the yield of ferric ions. This led to optimisation of the
formulation of the FXG radiochromic gel dosemeter material reported earlier [5] and [6]. Characteristics such as sensitivity, linear range, pre- and post-irradiation stability were studied as a function of the concentration of the three active constituents, ferrous sulphate, sulphuric acid, and xylenol orange; for a linear dose range up to about 30Gy the respective optimum concentrations are 0.5, 25 and 0.1 mM respectively. Water and gelatin make up the bulk of the FXG dosemeter at approximately 94% and 5% respectively, which render the material highly soft tissue equivalent [4]. Fresh unirradiated FXG has a pale orange appearance and is highly transparent. Upon irradiation it begins to turn increasingly purple but remains transparent with no sign of turbidity. For calibration the optical absorbance is measured with a CamSpec double beam UV-visible spectrophotometer in PMMA cuvettes using a 1cm light path. The clarity of this material indicates that light scattering is small which suggests that optical tomographic readout with a broad-beam (i.e. un collimated) light source is possible. This offers the possibility for a large increase in readout speed compared with MRI or single beam (laser) readout techniques. In this contribution we describe one practical factor that may give us better understanding of the system and its optimised application that is the temperature.

3. FXG dose response

Storage conditions including temperature, light, humidity, etc., as well as the purity of the system materials may cause some changes with time, which may affect the gel reading in the absence of radiation. Ferrous ions in the gel slowly oxidize and hence FXG suffer from the same sort of pre-irradiation changes as the Fricke system. FXG was found to be sensitive to rising temperature, which enhances unwanted excitations of the dye molecules and causes an experimentally verified reversible changes in gel optical density.

The system zero-dose and the changes that occur in the unirradiated samples by self-oxidation are important limitations. Knowledge about these effects is required so that they could be subtracted from the actual dose reading. In many cases these effects exhibit important non-reproducibility and cannot be ignored, therefore normalizing all dosemeter reading to a control sample or background reading becomes important. FXG zero dose reading was found to be about 0.09 cm\(^{-1}\) at 585 nm. The amount of change in the optical density of FXG due to natural oxidation at room temperature was found to be about 0.7×10\(^{-3}\) cm\(^{-1}\) h\(^{-1}\) measured at the wavelength 585 nm [4]. In comparison the change due to 1Gy of radiation energy deposited is 84×10\(^{-3}\) at 585 nm, see figure 1.

![Figure 1. FXG dose response curves showing a linear relationship in the range 0–30 Gy.](image-url)
FXG upper dose limit can be chosen to suit a dosimetric problem under investigation. Practically this can be done by increasing the concentration of ferrous ions and xylene orange molecules on one hand or by controlling the system chemical yield by increasing sulphuric acid concentration [4]. Beyond the 30 Gy threshold FXG response become almost flat, the slope of the curve in this region is only about 8% of that in the 0–30 Gy range.

The optical absorbance readings of samples stored in the dark at normal laboratory temperature increases with time, figure 2a after a stable initial period of about 30 hours, figure 2b.

![Figure 2a](image1.png)  ![Figure 2b](image2.png)

**Figure 2a.** Effects of long storage time at laboratory temperature on the pre-irradiation reading of the gel

**Figure 2b.** Effects of short storage time, few days, at laboratory temperature.

### 4. Temperature effect

A set of FXG samples were placed in a temperature controlled water bath that can cool down to about freezing temperature as well as being able to raise the temperature to about 100°C. At the start of this experiment the water bath temperature was fixed at 4°C, and this temperature is achieved by all samples when placed in the bath for a time long enough for the sample to reach thermal equilibrium with the surrounding water. In practice they were left for more than 10 minutes, then samples were taken out one by one and evaluated at the 585 nm with a control sample in the reference beam of the spectrophotometer. The water bath temperature was risen up one step another measurements of all samples were made and so on, see figure 3.

Steady increase in absorbance goes faster when temperature reaches about 30°C. Absorbance reading then jumps up to a much higher value, however if the temperature continues to rise gel colour begins to fade slowly, see figure 3a. This may result from higher temperature effects on the active constituents but it might be a direct result of the changes happening in the physical state of the system material, i.e. the change from a semi-solid gel to a liquid. Finally, it was noticed that cooling down the samples can reverse the increases in FXG absorbance with temperature and hence this effects could be resulting from excitation process in the XO molecules rather than actual oxidation of ferrous ions and colour complex formation.
Figure 3. Effect of temperature on the unirradiated FXG set of samples, optical absorbance was measured at 585 nm.

5. Conclusions

One pronounced disadvantage of the FXG system, and generally any system depending on chemical reactions, is its poor storage stability. Temperature and other ambient conditions may cause problems since the optical extinction coefficient generally depends on these factors. These effects can be minimised by employing lower concentration of ferrous ions to start with and storing the materials in a refrigerator before use. Applying a correction factor to compensate for storage time is recommended. Rising temperature during irradiation can be ignored if the dosemeter materials kept after irradiation and during evaluation under controlled temperature. After all, FXG still presents a reasonably practical dosemeter that could be used to study a range of dosimetric problems, not only three-dimensional applications.

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