The radiochromic indicator using methyl red dye solution as a high-dose gamma-ray dosimeter application

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Abstract. The radiochromic indicator using the methyl red dye solution has been studied as a high-dose gamma-ray dosimeter. The indicator has been tested by irradiating using gamma rays with a $^{60}$Co source. The radiation dose was varied from 5 to 100 kGy with a dose rate of 5.5 kGy/h. The color change of the indicator solution caused by the radiation was characterized by using a UV-Visible spectrophotometer and a camera photograph. In addition, the color stability of the indicator is also studied by observing the effect of time and the storage in light and dark conditions. The effect of time after irradiation on the color of the solution has also been investigated. The methyl red solution indicator showed a radiochromic phenomenon color changes from red to dark red for a dose of 5–20 kGy, faded gradually then became colorless at a dose of 25–100 kGy. These color changes correspond to the peak of the UV-Visible absorbance spectrum at a wavelength of 492 nm. The color of the indicator solution is more stable if kept in dark conditions than in the light conditions. The color of the solution also shows its stability for up to 12 days after irradiation. These results conclude that the indicator solution of methyl red can be used as a dosimeter for gamma rays in the dose range of 5–40 kGy.

1. Introduction

Dosimeters have an important role in the quality control of the radiation process [1]. There are several types of dosimeters, one of which is a radiochromic dosimeter that make use of the chemical structure changes of the dye of radiochromic indicator due to exposure to ionizing radiation. Ionizing radiation on a chemical compound can produce chemical changes to the compound and if the changes can be quantified it can be used as a technique to measure the absorbed dose [2]. Many dye solutions were used for this purpose, where the range of doses absorbed by the indicator can be determined by observing the color changes that occur in the indicator and the change in absorbance values, which can be observed by means of characterization tools such as photographic cameras and UV-Visible spectrophotometers.

Radiochromic dosimeter film has been widely developed as a high-dose gamma-ray dosimeter to observe the change in methyl red color due to gamma radiation in basic and acidic solutions [3,4]. The result in the base medium was exponentially reduced as the absorbed dose increased at the range of 50 Gy to 6 kGy, whereas the solution response in the acidic state decreased linearly as the absorbed dose increased up to 200 Gy. The PVB matrix added to the methyl red dye in various concentrations can be applied as a gamma radiation dosimeter with a range of 5–100 kGy, where dose sensitivity increases with increasing absorbed doses and concentrations of methyl red dye [5]. Kattan and Daher [6] reported that the radiochromic dosimeter of methyl red with the addition of PVC can be applied as a gamma radiation dosimeter at the range of 0–150 kGy.

The purpose of this study was to use a methyl red solution as a high-dose gamma-ray dosimeter, in which the solution would be observed both qualitatively and quantitatively to measure the range of...
2. Research procedure

2.1. Preparation of methyl red solution
Preparation of methyl red solution was done by dissolving 0.05 g of methyl red powder (Merck, Germany) in 100 mL of ethanol solution 99.9 % (JT Baker), with the pH value of the solution was 6.28. The solution was poured into a 2 mL ampoule by ¾ parts, which later on used as an indicator of methyl red solution. From the preparation of the solution, there were 50 samples of methyl red solution indicator weighed 1.24 ± 0.01 g.

2.2. Characterization of methyl red solution before irradiation process
Methyl red solution characterization before irradiation process using a UV-Visible Spectrophotometer (GENESYS) was conducted to observe the initial absorbance spectrum of the indicator prior to the exposure of gamma irradiation and the effect of environmental conditions. Characterization was done at wavelengths of 200–800 nm in ultraviolet and visible regions.

2.3. Gamma rays irradiation on methyl red solution
The methyl red solution indicator was irradiated using a Gammacell 220 irradiator with a Cobalt-60 source at the dose range of 5–100 kGy with dose rate of 5.5 kGy/h. The accuracy level of the methyl red solution indicator was observed by irradiation of 3 samples for each radiation dose.

2.4. Characterization of methyl red solution after irradiation process
Characterization of methyl red solution after irradiation using UV-Visible Spectrophotometer was performed to see changes in absorbance spectrum occurring on the indicator after exposure to gamma-ray radiation in various absorbent doses. An observation on absorbance spectrum stability was performed for 12 days post irradiation with 4 days time interval.

2.5. Test on the stability of methyl red solution to lighting condition
The stability test of methyl red solution was carried out by storing the solution in light condition (the solution was left in the room with lights) and in dark condition (where the solution was wrapped with aluminum foil to isolate the solution from the light). Afterwards, the characterization of methyl red solution was conducted to see the changes of absorbance value of the solution due to the lighting conditions.

3. Results and discussion

3.1. The response of methyl red solution indicator to the dose of radiation
The response of the methyl red solution indicator to the radiation dose has been investigated by irradiating the indicator with gamma rays at various absorbed doses. The color change from the indicator occurs with an increase in absorption dose up to 20 kGy, then undergoes a color fading of up to 100 kGy (figure 1). The color of the methyl red solution changes from red to dark red for a dose of
Figure 2. Absorption spectra of methyl red solution dosimeter as a function of wavelength for various absorbed doses.

Figure 3. The absorbance of methyl red solution at 492 nm as a function of absorbed dose (a) up to 40 kGy and (b) up to 20 kGy.

5–20 kGy, then fades and turns colorless gradually at a dose of 25–100 kGy. These color changes correspond to changes in absorbance spectra obtained from UV-Visible spectrophotometers.

Measurement of the change in absorbance peak of the methyl red solution was performed using a UV-Visible Spectrophotometer, where 1:8 dilution was performed on the methyl red solution test (1) using ethanol solvent (8). The absorption spectrum of methyl red solution at various absorption doses has been measured in the range 300–650 nm. Figure 2 shows a decrease in the absorption spectrum of the methyl red dye to an increase in absorption dose in the range of 0–40 kGy.

The dose response curve has been observed based on changes in absorption peaks defined at 492 nm against the absorbed dose. The dose response of the methyl red solution is shown in figure 3. The color bleaching of methyl red solution gradually intensifies as the absorbed dose is intensified up to 100 kGy, this can be confirmed by the lower absorbance value of the solution by the increase in absorption dose. as the absorbed increases, more hydrated electrons and free radicals are resulted, creating a breakage of an azo group of methyl red dye, generating the disappearance of a chromophore [7].
The accuracy of the methyl red solution as gamma-ray dosimeters has been observed by irradiating as many as 3 samples for each absorbent dose and obtained a precision error of <0.89%. The response curve of methyl red solution obtained showed that there was a sharp decrease in the absorbance value of the solution at a dose range of 5-20 kGy then at a dose range of 25-40 kGy, there was no significant decrease.

3.2. Stability of methyl red solution before irradiation (shelf life)

Measurement of stability of the methyl red solution before irradiation is done by storing the solution in dark and light conditions at room temperature. Figure 4 shows absorbance peak changes of the solution for 3 weeks at 1 week intervals (with 1: 8 dilution using ethanol solvent).

Observations were made at a wavelength of 492 nm. It was observed that the absorbance value of the methyl red solution in dark storage conditions did not change during 3 weeks of storage. Meanwhile, the methyl red solution stored in light conditions has increased the absorbance value gradually. This indicates that the methyl red solution indicator is more stable when kept in dark conditions for 3 weeks of storage before irradiation.

3.3. Post-irradiation stability

The indicator stability of methyl red solution after irradiation was tested by observing the change in absorbance of methyl red solution at a wavelength of 492 nm. Observations were made on methyl red solution during 12 days of storage after irradiated at a various absorbed dose.
solution which was irradiated at doses of 5, 10, 20 and 30 kGy and measured every 4 days for 12 days after irradiation. The results are shown in figure 5, where there was no significant change in absorbance from the indicator of methyl red solution up to 12 days measurement. This indicates that the methyl red solution has a good stability for up to 12 days after irradiation with a wide range of doses.

4. Conclusions
The methyl red solution indicator is sensitive to the dose of radiation, where the color change and the absorbance value decreased as the radiation dose increased. The methyl red solution indicator can be observed both qualitatively and quantitatively. Qualitative methods was done by observing the color change of the indicators using photographic cameras, while the quantitative method used UV-Visible Spectrophotometer. The methyl red solution has a good linearity at the dose range of 5–20 kGy with a precision error <0.89%. The methyl red solution indicator is more stable when kept in dark conditions for up to 3 weeks of storage before irradiation and stable for up to 12 days post-irradiation.

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