Comparative study of the dose rate influence in the radiochromic polymeric film dosimeter response

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Abstract. Most of film dosimetry is based on optical signal measurements since the spectrophotometric technique is cheap and widespread. Radiation induced chemical reactions take place in the material creating and/or enhancing absorption bands in the visible and/or ultraviolet regions of the spectrum. The response of most films used in routine dosimetry is usually influenced by the environmental conditions (temperature, humidity, light), dose rate and post irradiation storage. Several film dosimeters are commercially available for the absorbed dose measurements, in this work the effects of dose rate changes in optical density (OD) of film dosimeters (polymethylmetacrylate – PMMA) and polycarbonate – PC) were investigated and compared. Polycarbonates has been investigated as a new dosimetric material for industrial radiation processing aiming low cost, easy handle, fast and accurate response. PMMA dosimeters has been used routinely in dosimetry. The dose rate (kGy h\(^{-1}\)) may influence the dosimeter response and appropriate corrections are necessary. The dosimeters were irradiated with \(^{60}\)Co gamma-radiation at dose rate in the range 0.26 – 2.6 kGy h\(^{-1}\) and with electrons from accelerator with maximum energy of 1.5 MeV and dose rate between 4.19 and 33.59 kGy s\(^{-1}\) to absorbed doses of 5 and 15 kGy, respectively. The irradiated dosimeters were measured using Shimadzu UV-2101PC spectrophotometer. It can observed that the films shows moderate dose-rate dependence (about 10%) in the analysed range.

1. Introduction
Effects induced by ionizing radiation (accelerated electrons, ion and protons, gamma and X rays) have been largely used to modify the chemical and physical properties of the polymers [1,2]. Some of the changes have been attributed to the scissioning of the polymer chains, breaking of covalente bonds, promotion of cross-linkages, formation of carbon clusters, liberation of volatile species and, in some cases, even formation of new chemical bonds [3-5].

Polycarbonates are usually applied in neutron and alpha particles detection using nuclear tracks detection technique now a days has been studied as a dosimeter to measure gamma-rays doses [6]. The ionizing radiation changes the color of polycarbonates of colourless to yellow-green. The radiolysis mechanisms of polycarbonates explain the formation of isolated phenoxy radicals (responsible for the yellowing) and two different radical pairs as well as the evolution of large amounts of CO\(_2\) and CO [7-9].
Several film dosimeters are commercially available and the PMMA is widely used as ionizing radiation dosimeter in industrial applications. The interesting effect induced radiation in this material is the color or optical density change that can be related to the absorbed dose [10-12].

Optical absorption is a useful method for investigations of the induced changes in the polymeric material. The dosimetric system is based on the measurement of specific optical absorbance k at 412 nm and 640 nm wavelength for PC and PMMA, respectively.

In this work the dose rate dependence response for PC and PMMA red 4034 perspex detectors was studied for photons and particles radiation using in gamma source and accelerated electrons of 1.5 MeV maximum.

2. Experimental

Polycarbonate (PC) sheets (2 x 1 m) manufactured by Policarbonatos do Brasil and commercially available 3 mm thick (crystal) and density 1.2 g.cm\(^{-3}\) was used for this work. The PC sheets were cut into strips 10 mm width and 30 mm length. Polymethylmethacrylate (PMMA), Harwell type Red 4034, is manufactured with a red dye, 3 mm thick, cut into ships 30 mm length, 10 mm width and sealed in laminated foil sachets.

Both samples were irradiated with \(^{60}\)Co gamma-rays using the Gammacell 220 source installed at the Radiation Technology Center – CTR / IPEN-CNEN/SP. The absorbed dose rate correspondig to 2.55 kGy h\(^{-1}\) in march/2008, was detemined by Fricke dosimeter and certified by IAEA. The PC and PMMA films were tested for dose rate dependence for total doses up to 5 kGy.

To evaluated the electron dose-rate dependence of the OA response, both samples were irradiated with 1.25, 1.311, 1.40 and 1.499 MeV electrons at doses rate between 4.19 and 33.59 kGy s\(^{-1}\) varying the current between 0.97 and 7.77 mA. The irradiation process was performed in a JOB-188 Dynamitron Inc. Electron Accelerator, IPEN-CNEN/SP.

The UV-Vis measurements were performed in the maximun wavelength using the Shimadzu UV-2101PC. Each data point represents an average of three measurements.

3. Results

Radiation induced damage in polymers depend on accumulated absorbed dose and can result in dramatic changes in the polymer structure on relatively short time scales.

The response of PC and PMMA samples irradiated with \(^{60}\)Co gamma rays with different doses rates, 0.255, 0.765, 1.275 and 2.55 kGy h\(^{-1}\) and 5 kGy is reported, figure 1 and 2, respectively. The dose rate at the studied range had no effect on the change of specific absorbance of the PMMA red 4034 perspex detectors, however, significant difference in the optical response was observed for differences of 10 times, in the rate dose at low doses for PC detectors; the influence at higher doses is being studied.

![Figure 1. Dose rate dependence response for PC samples irradiated with \(^{60}\)Co gamma radiation, measured at 412 nm wavelength.](image-url)
Figure 2. Dose rate dependence response for PMMA red 4034 Perspex irradiated with $^{60}\text{Co}$ gamma radiation, measured at 640 nm wavelength.

The optical response of PC and PMMA samples irradiated with electrons accelerated (absorbed dose of 15 kGy) in the conditions listed in the table 1 is showed in figure 3 and 4 for PC and PMMA, respectively. The change in the detectors response is less 10% between the maximum and minimum obtained values and 6% in average, demonstrating that there is no significant dependence of the response at different energies, currents and dose rates.

Table 1: Irradiation parameters – PC and PMMA samples irradiated in the JOB 188 electrons accelerator, IPEN-CNEN/SP.

| Irradiations Conditions | Energy (MeV) | Current (mA) | Dose rate (kGy/s) |
|-------------------------|-------------|--------------|-------------------|
| 1                       | 1.250       | 0.97         | 4.21              |
| 2                       | 1.250       | 1.89         | 8.39              |
| 3                       | 1.250       | 3.79         | 16.81             |
| 4                       | 1.250       | 7.57         | 33.59             |
| 5                       | 1.311       | 0.97         | 4.19              |
| 6                       | 1.311       | 1.94         | 8.39              |
| 7                       | 1.311       | 3.89         | 16.82             |
| 8                       | 1.311       | 7.77         | 33.59             |
| 9                       | 1.400       | 1.01         | 4.20              |
| 10                      | 1.400       | 2.02         | 8.41              |
| 11                      | 1.400       | 4.04         | 16.82             |
| 12                      | 1.400       | 8.07         | 33.59             |
| 13                      | 1.499       | 1.05         | 4.19              |
| 14                      | 1.499       | 2.11         | 8.42              |
| 15                      | 1.499       | 4.21         | 16.79             |
| 16                      | 1.499       | 8.42         | 33.59             |
Comparisons between Polycarbonate and PMMA detectors has showed that both presents convinient dosimetric response when irradiated with ionizing radiation, the changes in optical density are visible, measurable and can be related with absorbed dose. These dosimeters are easy to handle, low cost and can be used in a wide dose range.

Dose rate dependence may introduce large errors to the dose measured. To minimize these errors the detectors can be calibrate in the uses conditions or determinated these errors and made appropriate corrections of the reading.

The dose rate effect (gamma and accelerated electrons) in the studied range for PMMA detectors presents no significative dependence, so it can be used in varied conditions of irradiation.

PC detectors presents significative dependence in response in differents gamma dose rates in low dose. This suggests that it should be used in a range of higher doses, research to determine this effect are being made. No significative effect was observed in irradiations with accelerated electrons.

4. Conclusions

Figure 3. PC detectors irradiated with electron accelerated, dose 15 kGy.

Figure 4. PMMA red 4034 Perspex detectors irradiated with electron accelerated, dose 15 kGy.
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