DETERMINATION OF THRESHOLD RADIATION DOSE IN THE DEGRADATION PROCESS OF INDIGO DYE BY GAMMA IRRADIATION TECHNIQUE

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ABSTRACT
Irradiation of indigo dye samples with gamma radiation at different radiation doses reveal that as radiation dose is increased the absorbance of the dye decreases. At the radiation dose of 0.6 kGy the spectral peak of the dye samples completely disappears indicating complete degradation of the dye. It is further observed that the behavior/decrease in absorbance of the dye samples has a peculiarity at the radiation dose of 0.3 kGy. Such peculiarity is also clearly observed in the curves for absorbance versus radiation dose, Full Width at Half Maximum (FWHM) versus radiation dose, peak height versus radiation dose and change in base points versus radiation dose. The possible implication of these observations is discussed.

Keywords: Radiation Dose, Degradation, Absorbance, Irradiation

INTRODUCTION
When indigo dye solution was exposed to optical radiation sources such as mercury light (at low pressure) and sunlight (at 3.00 pm) the absorbance of the dye consistently increased with increase in exposure time[1]. However, irradiating the dye with high-energy radiation sources like gamma radiation and neutron led to gradual decrease in absorbance of the dye with increase in radiation dose such that at the dose of 0.6 kGy the spectral peak of the dye completely disappeared[2]. This demonstrates that optical radiation sources and ionizing radiation sources exhibit different effects on the spectral peak of the dye.

THEORETICAL CONSIDERATION
High-energy radiation such as gamma radiation and neutron radiation carry much higher energy when compared to optical radiation such as solar radiation or radiation released by mercury and cadmium light. The high energy radiation therefore has high linear energy transfer LET and so deposits huge energy to receiving medium. It is called ionizing radiation because deposit of the energy to receiving medium leads to formation of ions in the medium.

INTERACTION OF IONIZING RADIATION WITH INDIGO DYE SOLUTION
When ionizing radiation such as gamma radiation interacts with indigo dye solution it energizes the water molecules that form the dye solution. This leads to ionization of the water molecules which subsequently results in creating reactive radicals called hydroxyl ion (OH^-) and hydrogen ion (H^+)[3]. These radicals attack the colour-bearing chromophores of the dye molecule thus degrading the dye or making it incapable of imparting blue colour on white fabric during the dyeing process[5]. The process leading to production of these reactive radicals takes place in three stages as:

Initial Physical Stage: This stage lasts for about 10^{-18} second in which energy is deposited to a water molecule which forms the dye solution. This causes ionization as:

$$H_2O^+ \xrightarrow{radiation} H_2O^+ + e^- \qquad\qquad (1.1)$$
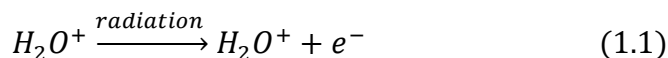
The positive and negative ions produced in the initial stage undergo further reaction in the next stage:

i. **Physico-Chemical Stage:** This stage lasts for about 10^{-6} second and the positive ion previously produced in the initial stage undergoes dissociation as:

$$H_2O^+ \rightarrow H^+ + OH \qquad\qquad (1.2)$$

The negative ion (electron) attaches itself to a neutral water molecule to form a complex which then dissociates as:

$$H_2O + e^- \rightarrow H_2O^-$$

$$H_2O^- \rightarrow H + OH^- \qquad\qquad (1.3)$$
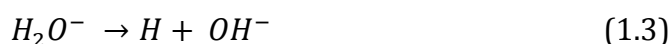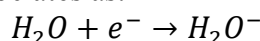
The time dependence of dye disappearance can be described by the differential rate equation

$$-\frac{d(Dye)}{dt} = k[l][(Dye)] \qquad\qquad (1.4)$$

Where [Dye] represents the dye concentration, [I] is the intermediate radical concentration and k is the second order rate coefficient [6].

METHODOLOGY

Indigo dye solution (1 liter) was directly collected from one of the dye pits at Kofar Mata dyeing center in Kano City. It was collected in amber plastic bottle (to protect it from sunlight) and taken to the dark room. About 75 ml of the dye solution was added into each of six (6) smaller bottles and the bottles were labeled to indicate their respective radiation doses with variation of the radiation doses being at intervals of 0.1 kGy. The bottles were then irradiated using gamma irradiation facility (GIF) as per the labels on the bottles. The absorbance of the irradiated dye samples were measured using spectrophotometer 752s across the spectral region of the dye. Curves for absorbance against radiation dose were then plotted to study the response of the spectral peak with increase in radiation dose.

RESULTS AND DISCUSSIONS
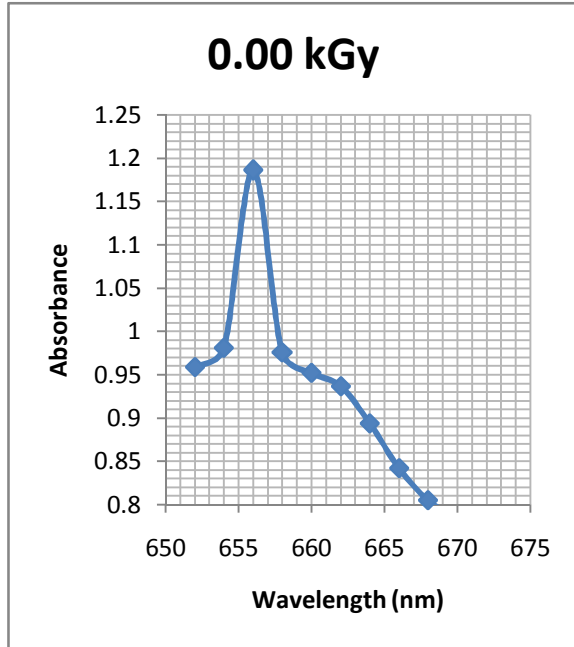## Results

Fig.4.1   Absorbance of un-irradiated dye samples
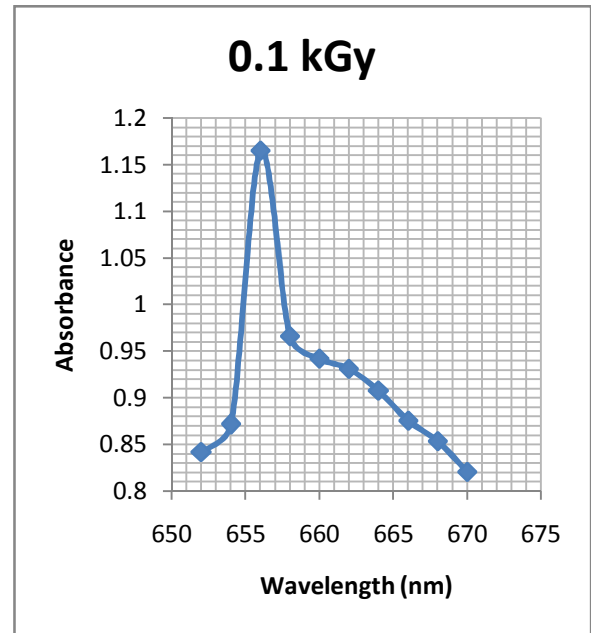with wavelength

Fig. 4.2   Absorbance of sample irradiated at 0.1
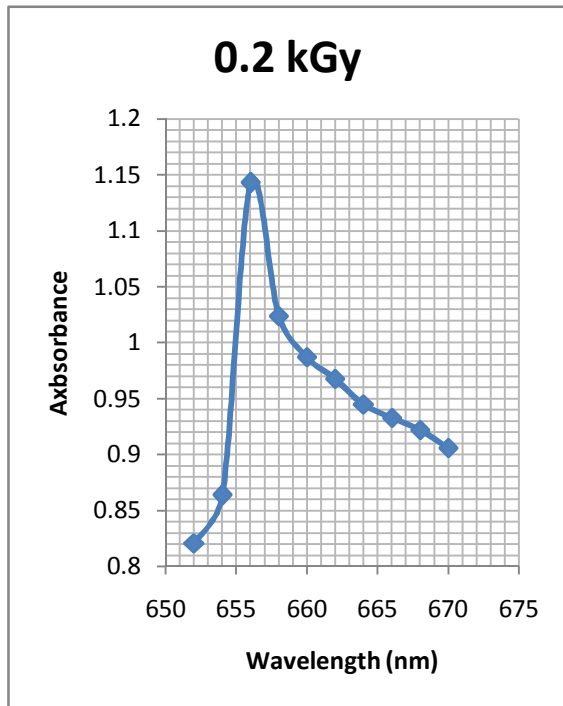kGy with wave length

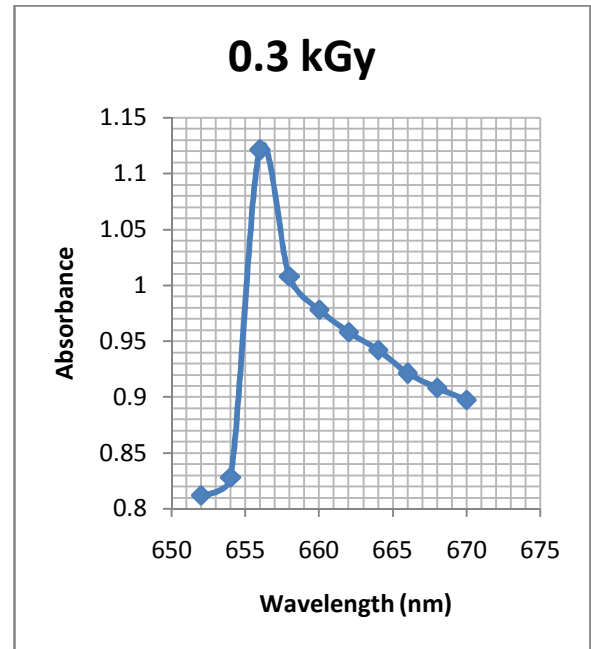Fig.4.3   Absorbance of sample irradiated at 0.2
kGy with wave length

Fig. 4.4   Absorbance of sample irradiated at 0.3
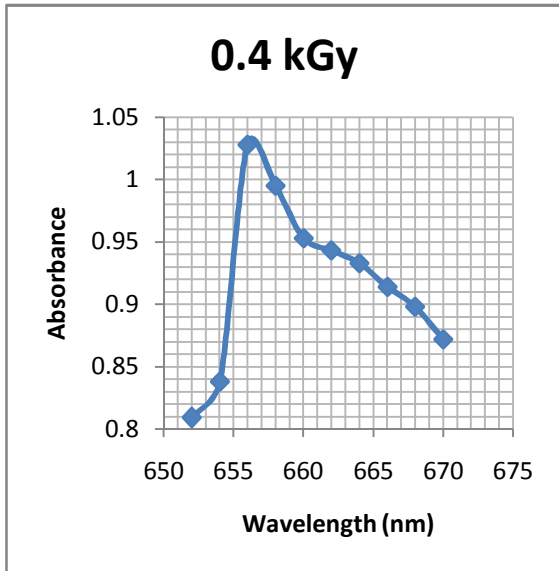kGy with wavelength

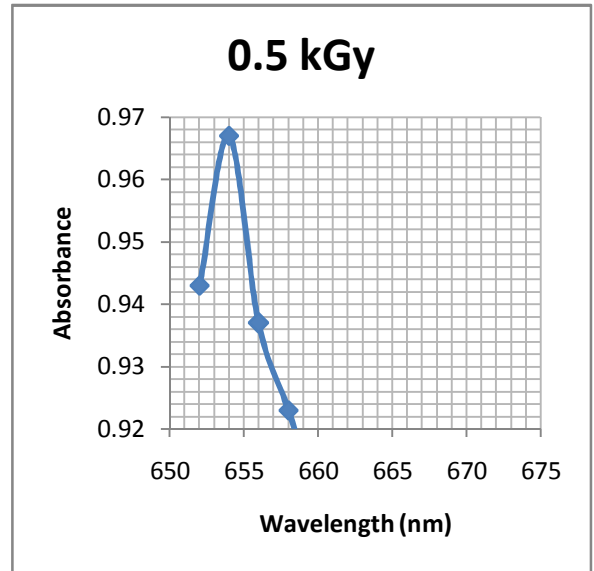**Fig. 4.5   Absorbance of sample irradiated at 0.4kGy with wave length**

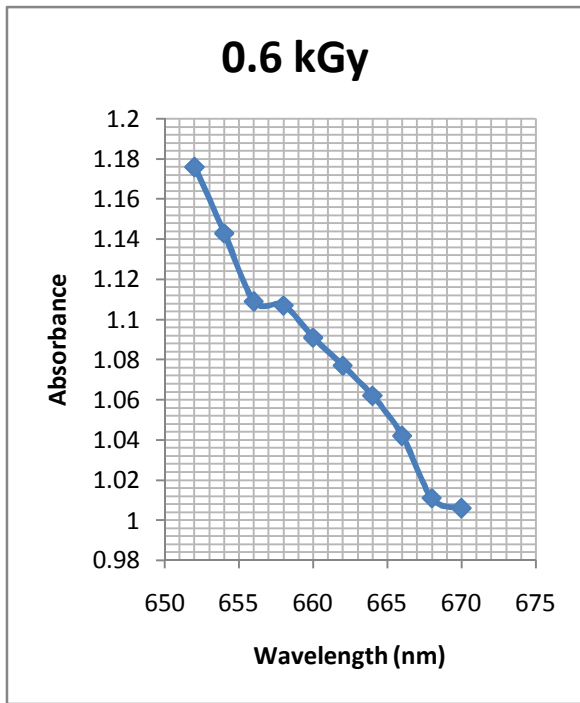**Fig.4.6   Absorbance of sample irradiated at 0.5kGy with wave length**

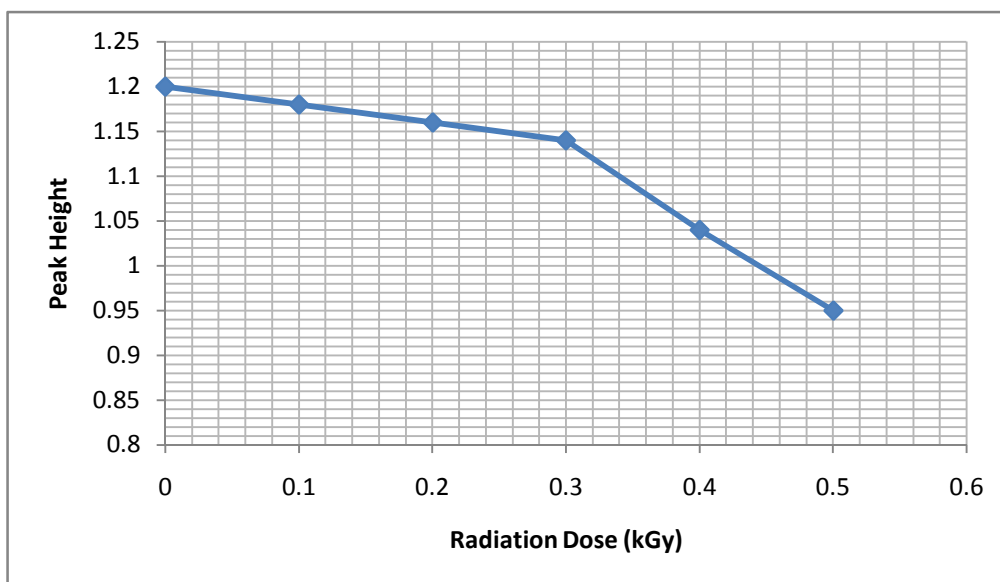**Fig. 4.7   Absorbance of sample irradiated at 0.6kGy with wave length.**

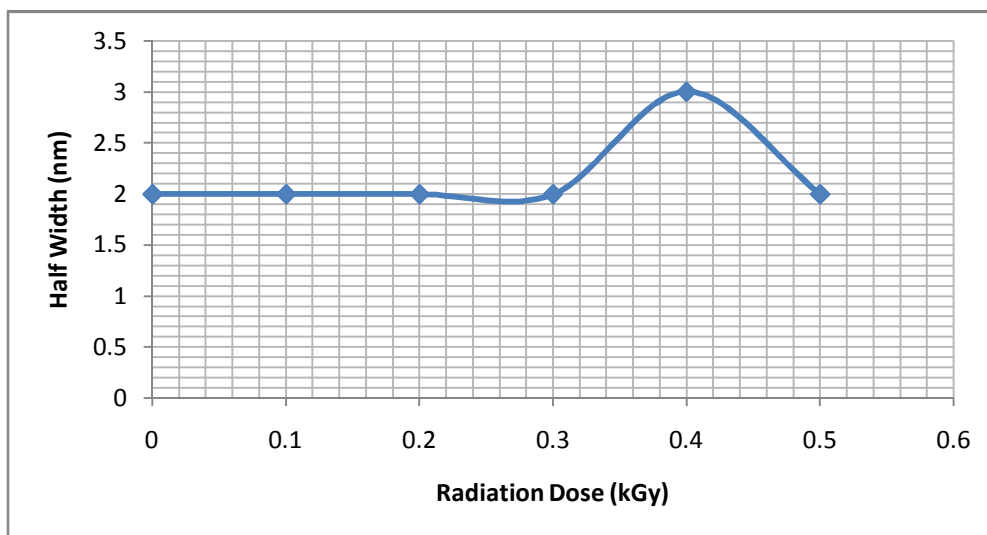**Fig. 4.8: Peak Heights as a function of Radiation Dose**

Fig. 4.9: FWHM as a function of Radiation Dose

DISCUSSIONS

Figure 4.1 to Figure 4.7 show the response of the spectral peak of the dye with increase in radiation dose. Looking closely at the curves (Figure 4.1 to Figure 4.7) it is observed that parameters such as peak height, FWHM and difference in base points do change with increase in radiation dose. Data collated with regards to such changes of the mentioned parameters are graphically illustrated as in Figure 4.8 to Figure 4.10.

Figure 4.8 shows the curve for peak height with increase in radiation dose. It is evident from the curve that as radiation dose increases the peak height decreases [7]. The decrease is gradual and steady for low radiation doses and rapid for higher doses. In fact the average gradient of the curve between the radiation doses of 0.0 kGy to 0.3 kGy is 0.2 nm/kGy while the gradient beyond 0.3 kGy (0.3 kGy to 0.5 kGy) is 0.95 nm/kGy [8]. This implies that the decrease in peak height beyond the radiation dose of 0.3 kGy is more than four times faster when compared with the decrease of the peak height at lower radiation doses. The behaviour of this radiation dose (0.3 kGy) looks strange and suggests a special peculiarity for such radiation dose.

The curve in Figure 4.9 illustrates the response of full width at half maximum (FWHM) of the spectrum of the dye as radiation dose increases. This parameter (FWHM) remains constant for the radiation dose 0.0 kGy to 0.3 kGy. Beyond 0.3 kGy the parameter increases to a maximum value of 3 nm at the radiation dose of 0.4 kGy and finally decreases to 2 nm at the dose of 0.5 kGy. This also portrays the peculiarity of the radiation dose (0.3 kGy).

Figure 4.10 illustrates the relationship between the difference in base points and the radiation dose. The curve in this Figure shows that the difference in base points

increases gradually from 0 to the maximum value of 0.18 at the radiation dose of 0.3 kGy. It then decreases to the minimum value at the dose of 0.5kGy. This observation also confirms the peculiarity of this radiation dose (0.3 kGy).

The peak height, the full width at half maximum as well as the difference in base points of the peak try to show the extent to which the peak of the dye loses its size, shape and symmetry as radiation dose increases leading to its (peak) eventual disappearance at the dose of 0.6 kGy[7]. Looking closely at the curves of these three parameters it may be observed that the parameters exhibit inverse relationship with one another. It is also evident from the curves that their behaviour at the radiation dose of 0.3 kGy is very strange. This radiation dose seems to be the turning point in the range of the radiation doses that lead to degradation of indigo dye through gamma irradiation technique. It is therefore finally suggested that 0.3 kGy is the threshold radiation dose in the degradation process of indigo dye.

CONCLUSION

Results obtained show that irradiating the natural indigo dye solution with gamma radiation leads to degradation/decolourization of the dye solution. Degradation/decolourization of the dye is achieved at the radiation dose of 0.6 kGy. 0.3 kGy is the threshold radiation dose in the degradation process of natural indigo dye solution.

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Reference to this paper should be made as follows T.S. Bich *et al.,* (2013), Determination of threshold radiation dose in the degradation process of indigo dye by gamma irradiation technique, *J. of Physical Science and Innovation Vol.5, No.1, Pp. 15-22.*

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