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Research Paper

Effect of pH of Water on Absolute Dosimetry Using TRS398 Protocol

Ige T. A.[1,✉], Adewole M.[1], Opadele A.[2], Ekpo M.[3]

1. Department of Medical Physics, National Hospital, Abuja, FCT, Nigeria
2. Department of Basic Sciences (Physics Unit), Babcock University, Ilishan-Remo, Nigeria.
3. Department of Physics, University of Ibadan, Ibadan, Nigeria.

✉ Corresponding author: Dr. Taofeeq A. Ige, Department of Medical Physics, National Hospital, Abuja, FCT, Nigeria. Tel: +2348023057308; E-mails: igetaofeeq@yahoo.com, taofeeqige@gmail.com

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Abstract

The IAEA published TRS 398 in 2000 to serve as a code of practice for the determination of absorbed dose to water in photon beams, electron beams, proton beams and heavy ion beams used for external radiation therapy. pH (potential of hydrogen) is a measure of the concentration of (H^+) in a solution; it ranges from 6.5-8.5 for water. In this study, an experiment was conducted to evaluate the effect of pH variation of the water phantom on charge collection and aimed to establish water pH correction factor (K_{pH}) as one of the correction factors for influence quantities of TRS 398. A water tank with the capacity of 27000cm^3 was filled with water with an initial pH of 7.3. This was varied from 3.0 to 10.0 using diluted hydrochloric acid (HCl) and sodium hydroxide (NaOH) across acidity and alkalinity lines respectively. The water tank was positioned under the LINAC at 100cm SSD with 10cm x 10cm field size. The chamber (SNC Farmer with calibration factor of 5.18 x 10^7 Gy/C) was placed at a depth of 10cm along the central axis of the beam. Repeated electrometer measurements were obtained with 100MU for 6MV, 10MV and 15MV respectively. Results from the study indicated that the measurement was dependent on the pH of the water phantom as the plots showed similar sinusoidal wave structures for all the three photon energies. It also revealed that maximum ionization was obtained when the pH is between the ranges of 8.0 to 9.0 for all energies. The analysis of the variation in the charge collected suggests that there is no rationale for evaluating the K_{pH} as the outputs were within the acceptable range.

Keywords: pH water; IAEA; absorbed dose; water phantom.

Introduction

The International Atomic Energy Agency (IAEA) introduced Technical Report Series No. 398 (TRS 398) for absolute dosimetry of photon beams in 2000 [1]. It serves as an update sequel to the TRS 277 and TRS 381. It is a Code of practice based on absorbed dose to water for the dosimetric evaluation of radiation beams. Such radiation beams include low-energy x-rays, medium-energy x-rays, Co-60 gamma radiation, high-energy photons, electrons, protons and heavy ions.

Chambers are set-up in Water filled phantoms at reference conditions and readouts are obtained on the electrometer. Such reference conditions include geometrical arrangement (distance and depth), field size, material and dimensions of the irradiated phantom, ambient temperature, pressure and relative humidity.

The absolute dose ($D_{w,Q}$) is given as:

$$D_{w,Q} = M_Q N_{D,w,Q_0} K_{Q_0} \quad (1)$$

where M_Q is the reading of the dosimeter incorporating the product $\prod k_i$ of correction factors for influence quantities, and k_{Q,Q_o} is the correction factor which corrects for the difference between the reference beam quality Q_o and the actual quality Q being used.

$$\Pi k_i = k_{TP} \times k_{pol} \times k_s \times k_{elec} \quad (2)$$

where:

- k_{TP} = correction for temperature, pressure and humidity
- k_{pol} = correction for chamber polarity
- k_s = correction for ion recombination
- k_{elec} = correction for electrometer calibration

$$k_{TP} = \frac{(273.2+T)P_0}{(273.2+T_0)P} \quad (3)$$

T and P being the cavity air temperature and pressure at the time of measurement respectively. P_0 and T_0 are the reference condition of 101.3 kPa and 20°C respectively.

$$k_{pol} = \frac{|M_+|+|M_-|}{2M} \quad (4)$$

where M+ and M– are the electrometer readings obtained at positive and negative polarities, respectively, and M is the electrometer reading obtained with the polarity used routinely (positive or negative).

K_{elec} is usually unity as both chamber and electrometer are usually calibrated together. But in instances where they are not, it could be obtained from the calibration laboratory.

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 \quad (5)$$

where k_s is the polarity correction factor. pH is a measure of the concentration of protons (H+) in a solution. S. P. L. Sørensen introduced this concept in the year 1909. The p stands for the German potenz, meaning power or concentration, and the H for the hydrogen ion (H+) [2].

The pH of distilled water is 7. In general, water with a pH lower than 7 is considered acidic while water with a pH more than 7 is considered basic (alkaline). The pH for surface water systems ranges from 6.5-8.5 while that of groundwater ranges from 6-8.5 [3].Water has been shown to behave differently based on the level of these radicals inside it [2].

This study seeks to investigate the effect of megavoltage photon beams on water as its pH is varied. It also aims to verify the influence of this effect on TRS 398 used in the absolute dosimetry of photon beams and consequently derive the k_{ph} – correction factor for pH of the Dosimetric medium.

Lunec and Parker [4] demonstrated the influence of pH on the enhancement of radiation damage by hyperthermia when HeLa-S3 was treated with heat and/or radiation in medium of pH 7.4 or 6.7. The result showed that marked radiation sensitization of the survivor cells were observed but only slightly more at pH 6.7 than at pH 7.4.

Buchanan, Edelson and Boyd [5] investigated the effects of pH and acid resistance on radiation resistance of enterohemorrhagic Escherichia coli when seven enterohemorrhagic strains and one non-enterohemorrhagic strain were isolated. The cultures were adjusted to between 4.7 and 7.2 pH values using acidogenic and nonacidogenic media. These cultures were then irradiated using Cs-135 source. The results indicated that pH and acid have an influence on the radiation resistance of enterohemorrhagic Escherichia coli. These studies indicate that the reaction of matter with radiation varies differently based on the pH of the matter.

Materials and Methods

ELEKTA Synergy Linear Accelerator (Linac)

This machine also known as NHALINAC01 was manufactured by ELEKTA and has 80Multileaves Collimators (MLC's). It was used to generate photon beams of 6MV, 10MV and 15MV for this study. It is equally capable of producing electron beams. Repeated 100 Monitor Units (MU) at 10 x 10 cm field size were produced by the machine for all the three energies.

SNC 600 Farmer Chamber

This farmer-type chamber is manufactured by Sun Nuclear (SNC), and it was used to take measurements of the charge collected along the central axis of the beam.

SNC 1D Water Tank

The water tank also manufactured by SNC was filled with water to the 30cm mark. The farmer chamber was placed at 10 cm depth from the surface of the water. The surface of the water was adjusted to be 100cm from the source in the LINAC head. This was done with the aid of an Optical Distance Indicator (ODI).

SNC PC-Electrometer

The Farmer chamber was connected through a coaxial cable to a PC Electrometer (PCE) hardware and thereafter connected to the PCE software on a laptop through a USB cable. Repeated charge measurements were taken from this software and recorded.

Dilute NaOH and HCl Solution

Diluted Sodium Hydroxide (NaOH) and Hydrochloric Acid (HCl) solutions were used to alter the alkalinity and acidity of the water in the 1D Tank. Each was introduced into the 1D tank using a syringe.

pH Meter

This meter was used to measure the pH of the solution. It is an electronic meter with a three-digit LED display. It is capable of displaying equivalent readings for all the ranges of pH.

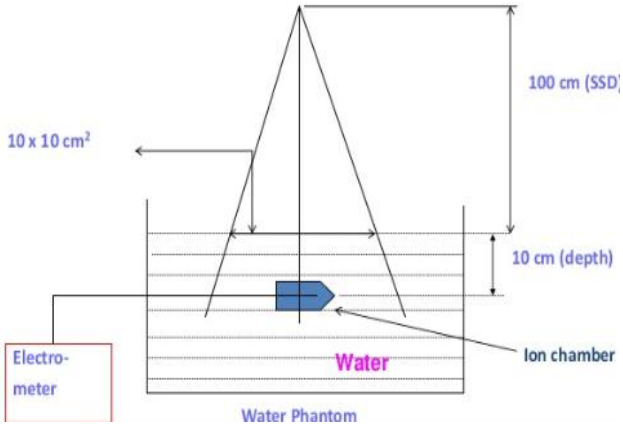

Figure1. **Setup of the study.**

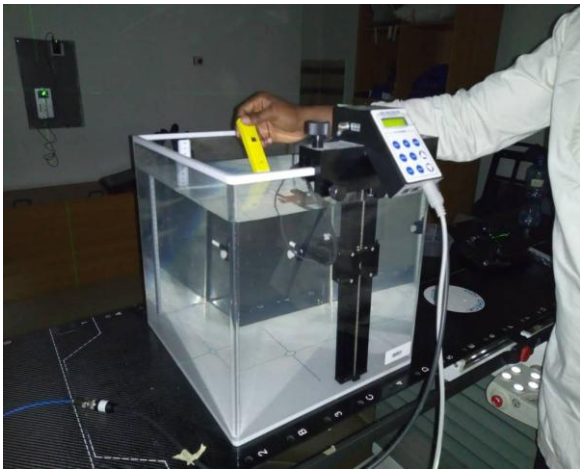

Figure 2. **The setup while the pH of the water is being measured.**

The Figure 1 above shows the setup of the experiment. It shows the 10 x 10 cm² field size, the chamber positioned at 10cm depth along the central axis of the beam and connected to the electrometer.

Results

6 MV Photon Energy

The charges collected for 100MU of 6MV photon beams are shown in Table 1 with the corresponding pH for 6MV.

Table 1. Charges collected with corresponding pH for 6MV

S/N	pH	Charge (nC)
1	3.400	12.017
2	5.100	12.003
3	7.250	12.143
4	8.750	12.164
5	10.050	12.084

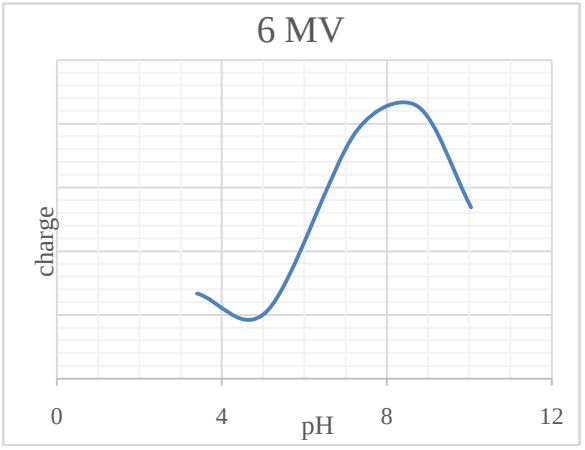

Figure 3. **A plot of the charge collected with the pH for 6MV.**

10 MV Photon Energy

The charges collected for 100MU of 10MV photon beams is as shown in Table 2 with the corresponding pH.

Table 2. Charges collected with corresponding pH for 10MV

S/N	pH	Charge (nC)
1	3.400	12.957
2	5.050	12.942
3	7.250	13.048
4	8.450	13.070
5	10.100	12.994

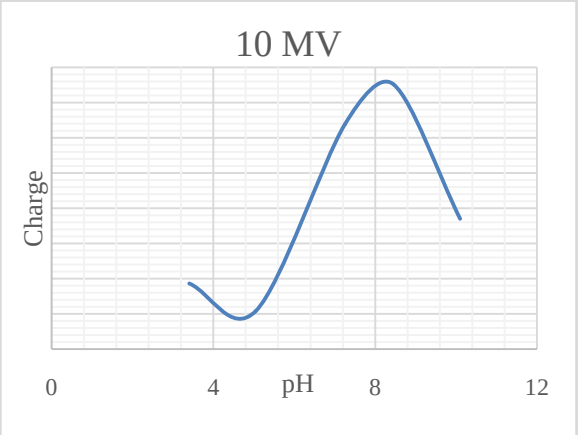

Figure 4. **A plot of the charge collected with the pH for 10MV.**

15MV Photon Energy

The charge collected for 100MU of 15MV photon beams is as shown in Table 3with the corresponding pH.

Table 3. Charges collected with corresponding pH for 15MV

S/N	pH	Charge (nC)
1	3.400	13.502
2	5.250	13.478
3	7.750	13.612
4	8.200	13.669
5	10.100	13.578

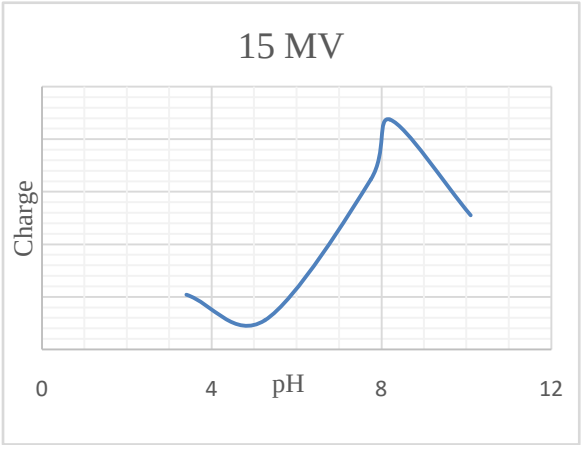

Figure 5. **A plot of the charge collected with the pH for 15MV.**

Discussion

Peak Ionization is observed for all energies at pH of 8.5 ± 0.2. The absorbed dose due to the charges collected were plotted into the table below. K_{TP} was calculated to be 1.0835. K_s, K_{pol}, K_{elec} was made to be 1 due to the fact that the factor is constant for the 3 energies in the scope of the research and $N_{D,W}$ = 5.18nC/Gy.

Table 4. Beam quality (KQQ0) and Percentage depth dose (%DD) for the three energies

	k_{QQ0}	%DD
6MV	0.990	0.673
10MV	0.998	0.729
15MV	0.977	0.761

The %DD in Table 4 above was extracted from the depth profile scan for the three energies while the K_{QQO} was extracted from the TRS 398, matching the chamber type to the $TPR_{20,10}$. The data in Table 4 was used to compute the absolute output of each charge collected. This is as shown in table 5.

Table 5. Dose output for the three energies based on the charge collected

S/N	pH	6MV (cGy/100MU)	10MV (cGy/100MU)	15MV (cGy/100MU)
1	3.4	99.21168	99.585586	97.28966
2	5.1	99.09885	99.465178	97.11432
3	7.25	100.2575	100.27986	98.07987
4	8.75	100.4253	100.45407	98.49059
5	10.05	99.77035	99.867394	97.83488

Table 5 above shows the dose output range from 97.29 cGy/100MU to 100.45 cGy/100Mu. To get a baseline for comparison, the result of the most recent TRS 398 on the machine was extracted and as shown in table 6.

The relative difference from the output calculated from the charge collected and the most recent absolute dosimetry on the LINAC is as shown in table 7.

Table 6. Most recent LINAC Absolute Dose Values

S/N	MV	cGy/100MU
1	6	100.0
2	10	100.4
3	15	98.2

Table 7. Relative difference in output for all energies

S/N	pH	6MV	10MV	15MV
1	3.4	-0.7883	-0.8112	-0.9270
2	5.1	-0.9012	-0.9311	-1.1056
3	7.25	0.2575	-0.1197	-0.1223
4	8.75	0.4253	0.0539	0.2959
5	10.05	-0.2297	-0.5305	-0.3718

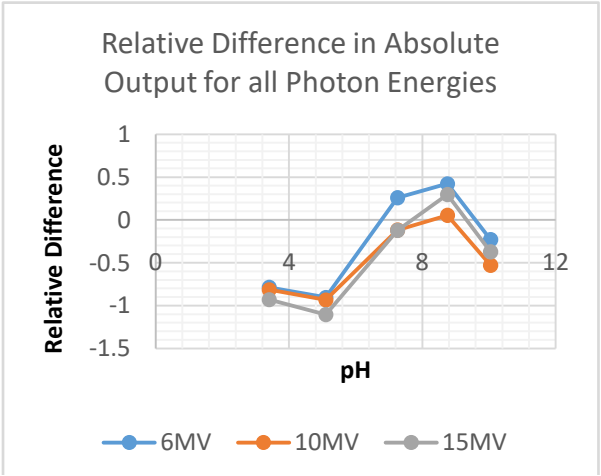

Figure 6. **Plots of the charge collected with the pH for 6, 10 and 15MV's.**

Figure 6 above shows that these three energies react the same way to changes in the pH of the Dosimetric medium. The absolute dosimetry ranges from 99.099cGy/MU to 100.4253cGy/MU for 6MV, while for 10MV the absolute dosimetry ranges from 99.469cGy/MU to 100.4538cGy/MU. For 15MV, the absolute dosimetry ranges from 97.0944cGy/MU to 98.4959cGy/MU. With these three energies, the highest variation is recorded on 15MV with 1.376%, this is within the 2% tolerance range according to IAEA TRS 398.

Conclusions

The pH of water influences the charge collected when megavoltage photon beams are incident on it. The behaviour of charges collected when the pH is varied exhibit the similar variation characteristics for the three energies. These variations when computed into absolute dose shows little variation from the result of the most recent absolute dosimetry. These variations are not significant enough to warrant deriving the k_{pH} as it is within less than ± 2%, the approved standard according to IAEA. Although the pH of the water for dosimetry should be kept as close as possible to 8, further research is recommended to investigate other parameters that may influence varying the pH in similar medium which may then give credence to the derivation of k_{pH}.

Abbreviations

ODI: Optical Distance Indicator; TRS: Technical Report Series; MLC: Multileaves Collimator; MU: Monitor Units; LED: Light Emitting Diodes.

Author Contributions

All authors contributed equally to this study and gave their final approval.

Competing Interests

The authors have declared that no competing interest exists.

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