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Application of Gamma Irradiation in Groundwater Treatment Using Different Techniques

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ABSTRACT

The different pollutants in the groundwater can be successfully excluded using potential gamma irradiation. Smart gamma irradiation coupled with ozonation can degrade most of the organic pollutants. Many pollutants' parameters can be managed, such as total organic carbon (TOC), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), and turbidity. The disinfection of many bacterial cells has been successfully performed besides the deactivation of rotavirus. Based on this manner, the simulated triclosan (TC) can be completely degraded using two techniques of irradiation: reduction and oxidation status. The metals polluting the understudied groundwater can be nearly completely removed by using gamma irradiation under reduction conditions. The applied gamma irradiation can precipitate metal ions such as cadmium, mercury, and lead (in atomic form) in the simulated wastewater, and groundwater. Different patterns seriously influenced the metal ions removal, such as different hydroxyl scavenges and sample gassing with different gasses (hydrogen, nitrogen, and air). This technique results in metal ions decontamination yielding 99.4%, 97.8%, and 96.9%, for cadmium, mercury, and lead ions respectively at the optimum conditions.

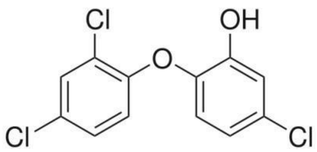
INTRODUCTION

A promising technology is the use of gamma radiolysis to treat wastewater and groundwater in the environment; the chemistry of this technology is being studied (Kucharski *et al.*, 2022);(Chien *et al.*, 2019);(Fekete *et al.*, 2017).

Recent research has shown that the gamma radiation process is a viable new way to get rid of organic contaminants in water ((Huang *et al.*, 2021), (Dantas-Torres & Otranto, 2020), Furthermore, the combination of ozone and gamma irradiation was applied in groundwater or drinking water remediation and reduced the dose rate value (Albalgane *et al.*, 2022). This mentioned technique is more advantageous than the traditional one in ease, rapidness, and yielding (Benoit *et al.*, 2018).

To efficiently remove the target chemical pollutant, one should also be concerned with the elimination of a series of intermediates with successively higher or lower oxygen-to-carbon ratios that are involved in the conversion of an organic molecule to carbon dioxide (Sánchez-Polo *et al.*, 2019).

A sample of pharmaceutical products such as triclosan (TC) in wastewater and groundwater causes serious problems during treatment.



Triclosan Molecular Structure

A change to the aquatic ecosystem and a danger to aquatic fauna (Sanchez-Vega *et al.*, 2018)and adverse human health effect has been noticed by increasing the TC in the understudied wastewater, and human health (Gallo *et al.*, 2019). Different techniques are in need and strongly required to complete the removal of TC. Partially degradation of TC upon using solely radiation under reduction conditions has been conducted (Bertucci *et al.*, 2017), so radiation coupled- ozonation is appreciated to be applied to fully get rid of them (Chou *et al.*, 2018). Many researchers have worked very hard to ultimately exclude the proposed TC; employing the gamma radiation-linked adsorption approach, the removal yield reached 97% (Amano *et al.*, 2018). The addition of metal oxide to the TC-polluted wastewater has a dramatic role in their removal in the presence of radiation-coupled ozonation (McFarland *et al.*, 2018); (Dybala *et al.*, 2019) and/ or alternative oxidation method (Huang *et al.*, 2021).

Based on the exclusion of the major organics in the polluted wastewater results in the treatment of few frameworks like 'chemical oxygen demand' "(COD)", 'biological oxygen demand' "(BOD)", and 'total organic carbon' "(TOC)". While TDS is managed due to the precipitation of dangerous metal ions in the form of metal oxide (Huang *et al.*, 2021). This implanted technique has a powerful effect on water-bacterial disinfection besides the deactivation of many viruses including Rotavirus.

The toxic metal ions are so difficult to be excluded owing to their high solubility, mobility, and permanence in the wastewater. Moreover, many of these metals can bio-accumulate and be easy to enter the human body through the food chain, threatening their life (Osvaldo *et al.*, 2022).

The wastewater treatment mechanism can be summarized as; by water radiolysis, many radicals have been created. The emerged radicals potentially reacted indirectly with the water contaminants and excluded them (Wojnarovits *et al.*, 2020).

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Gamma radiation plays a potential role in the reduction of metal ions in wastewater to unstable metal ions' oxidation states, which is finally precipitated due to their further reduction to metal atoms (Dana *et al.*, 2020).

There are many parameters influencing the mentioned technique such as hydroxyl radicals' scavengers, which conduct a reduction condition. Many aliphatic alcohols can be applied as hydroxyl scavengers which rising the removal percentage of metal ions by using the mentioned technique. The hydroxyl radicals were scavenged and a reduction state was created using the function of organic compounds such as aliphatic alcohols.

This work aims to offer a new technique for groundwater treatment achieving highly purified water that can be consumed by the elderly, patients, infants, and highly sensitive people. In this manner, gamma irradiation coupled with ozonation can potentially degrade the organics-polluted simulated wastewater and real groundwater. Due to this reason, some patterns can be purified reaching an acceptable value for drinking purposes such as COD, BOD, TDS, TOC, and turbidity. Gamma irradiation potentially causes bacterial disinfection and deactivation of rotavirus. A sample of organic pollutants such as triclosan (TC) has been completely degraded using gamma irradiation under reduction and oxidation conditions. Gamma irradiation reduced some metal ions (Hg^{2+}, Cd^{2+}, Pb^{2+}) in simulated wastewater and real groundwater to atoms form, which can be precipitated and separated. Some impacts influencing metal ions irradiation-precipitation have been studied such as degassing and hydroxyl scavengers.

Experimental

Sampling site

The deep well in Muhayel Aseer, Kingdom of Saudi Arabia, served as the groundwater's source. The major data especially the cations are reported.

Figure 1 : Muhayel Asir situation (Suliman M. Al Humayed and ABIM, 2016)

MATERIALS AND METHODS

The cadmium, mercury, lead sulfate, and different alcohols were purchased from Aldrich, UK. Supelco provides triclosan as a recognised reference substance for use in pharmaceutical secondary standards, case 3380-34-5, the chemical formula $C_{12}H_7Cl_3O_2$, and a molecular weightt of 289.54. The commercial gasses (nitrogen and hydrogen) have been supplied by Egypt for industrial gas Co.

The Samples Preparation

The metal ions of Cd^{2+}, Hg^{2+}, and Pb^{2+} with purities of 99%, 99%, and 98% respectively in sulfate form have been used for the preparation of simulated metals solution. The concentration of triclosan and metal ions of 50 mmole/L has been prepared on a lab scale. The metal ion's groundwater concentration was 0.08, 0.04, and 0.02 mole/L for Pb^{2+}, Cd^{2+}, and Hg^{2+} respectively. 75 mL Pyrex glass ampoules of simulated and groundwater were chosen for subjected to ^{60}Co gamma. The understudied solutions might be created and maintained saturated with the gas by adding 'hydrogen' (H_2) or 'nitrogen' (N_2) to the solutions at a rate of 100 cm3/min. The radiation exposure was carried out at a specified dose rate (A dosage rate of 1.76 kGy/h per ISO/ASTM 51261(2004) was utilised (El-Toony *et al.*, 2020). Different doses (5, 10, 15, 20, 30, and 40 kGy) were applied (Zhu *et al.*, 2017). Aldrich Co., an English company, has provided the chemical reagents (metal sulfates and alcohols).

The radioactive samples were spun at 11,000 revolutions per minute for 5 minutes before being filtered via Millipore filters (HAWP 04700, 0.45 mm pore size). A glass bottle with a screw cap was used to store the filtered solution until analysis. This technique can monitor groundwater in a lab or real life (Herrmann & Gehringer, 2019).

Triclosan Degradation

For the sake of the estimation, the triclosan concentrations and their derivatives can be done using High-performance liquid chromatography (HPLC). An HPLC is described as Agilent 1200 Series, Agilent, USA with a C18 reverse-phase column (5 mm, 4.6 x 150 mm). The detector was used as a diode array detector (DAD), set to 200 ± 10 nm

with a 1 mL/ min, controlled flow rate at 30 °C. 70:30 ratio of water/acetonitrile was applied as a solvent and it raised to 90% of water after 3 mins passage while it retrieves to the original ratio of solvents after 3 mins later. The chlorophenol, dichlorophenol, and benzene, which are TC's intermediates, were determined using HPLC-MS with a solvent volume of 30 mL. For this, the aforementioned column was used in conjunction with a Shimadzu 2010EV mass spectrometer equipped with an ESI ion source (LC-MS 2010, Columbia, USA). A photodiode array (PDA) was used as the detector in conjunction with the HPLC (De Brey *et al*., 2019).
Analytical columns from Dionex RFICTM Lon-Pac AS 14 (4 x 250 mm) were employed in conjunction with ion chromatography to evaluate TC derivatives such Cl- ('Dionex ICS-2100', 'California', 'USA'). An injection volume of 25 mL was employed, and the effluent was a mixture of Na_2CO_3 (3.5 mM) and NaHCO3 (1.0 mM), flowing at a rate of 1.0 mL/min (Xiao *et al*., 2017).

Total Organic Carbon (TOC) Measurement

For measuring the TOC, the wastewater was sampled in high-density polyethylene (HDPE) bottles. The bottles were thoroughly washed with deionized water before their use in the desired application, while the samples were acidified until their pH reached about two. Then the samples were ready to be stored at low temperatures.
Before the samples' analysis, the infusion with N_2 gas to expel the dissolved carbon dioxide has carried out. As a catalytic oxidation approach, the determination of TOC required raising the temperature to 680 °C. A Teledyne Tekmar Analyzer with "NDIR" detector ("Teledyne Tekmar, Ohio, USA") was used to measure the TOC. The certified reference material for calibration was sent to Analytik Jena (Aziz *et al*., 2018).

Evaluation of COD, BOD, and Microbial Count

The CARY 50 model of UV/visible spectrophotometer was used. Spectroquant NOVA 30 was used to quantify the COD. While using the published standard procedure to measure the BOD (El-Toony *et al*., 2020).

Bacterial Investigation

A 100 mL sample each of groundwater and sewage was taken and the samples were then grown on the appropriate agar. After 24 hours of storage at 37 °C, all of the samples were analysed, and a binuclear microscope was used to look for bacteria (Abdel-Shafy *et al*., 2020).
The Colony counter Stuart-SC6PLUS, England was used to assess the bacteria
l colonies (Elmorsy *et al*., 2019).

Inorganic Measurements

Cations

With a confidence of roughly 99% for the studied concentrations, the understudied cations were examined using the Unicam, Solaar 939, atomic absorption spectrophotometer (AAs). The apparatus is composed of a graphite tube, D2-background correction, electro-thermal atomizer PU 9390, PI computer, Win3.11 software, and a power source. The PPB family of AAs evaluates cadmium, lead, and mercury.

Table 1: Effect of simulated wastewater, groundwater purification, and gamma irradiation linked ozonation

				Removal%		
No.	**Water type**	**Scavengers**	**Gassing**	**Cd**	**Hg**	**Pb**
1-	Bi-distilled water	Methanol	Air	98.3	96.1	95.5
2-			Hydrogen	99.4	97.8	96.9
3-			Nitrogen	99.1	97.2	96.1
4-		Ethanol	Air	95.0	94.8	93.5
5-			Hydrogen	97.8	96.7	95.9
6-			Nitrogen	97	95.6	94.7
7-		Iso-propanol	Air	94.6	92.7	91.9
8-			Hydrogen	96.9	95	93.8
9-			Nitrogen	95.7	93.4	92.7
10-	Groundwater	Methanol	Air	76	68	64
11-			Hydrogen	86	79	77
12-			Nitrogen	81	74	70

RESULTS AND DISCUSSION

Utilising Gamma Irradiation and Associated Ozonation, Organic Contaminants are Degraded and Microbial Cells are Disinfected

The research on a variety of factors, including turbidity, "TDS," "COD," "BOD," "TOC," bacterial colony counts, and "Rotavirus detection," that are utilised as indicators of water pollution has been summarised in Table (1).
As part of the gamma irradiation process, the wastewater absorbs the radiation's energy, creating a number of key byproducts. As a result, hydrated electrons (e-aq), hydrogen radicals (H.), hydroxyl radicals (. OH), and less reactive species (H_3O+) have all been produced (Van Bruggen *et al*., 2018). Such generated active items have

a powerful effect on the ridding of different pollutants.

Among the mentioned active items, the nonselective hydroxyl radicals represent the most rapid and strong attack on the organic compounds. Two mechanisms explain the. OH, viability to exclude the organics that polluted the water. The first mechanism is based on the elimination of H from X-H (while X is N, C, or S). The second mechanism depends on an oxidation-reduction reaction or addition to unsaturated organic molecules (Shapiro *et al*., 2018). While in the presence of dissolved oxygen in water, the previously mentioned mechanisms will be more active and viable (Shi *et al*., 2020).

Upon exclusion of organics based on the mentioned mechanism or others, many items have been managed. Such items are water turbidity, TOC, and COD. Gamma irradiation has a potential effect on reacting with bacterial cells and destroying them and reducing their count (Rostamzadeh *et al*., 2018), and as a consequence, the BOD was managed. The sole gamma irradiation of metal ions harms the metal ions precipitation which results in a decrease in TDS values (Shen *et al*., 2019). The coupling of ozonation to the gamma irradiation technique raised their effect potentially on the organics degradation and metal ions precipitation. The metal ions' precipitation is based on the oxidation of them to stable metal oxide.

Numerous inorganic anions are strongly affected by the aforementioned approach. The degradation of carbonate and bicarbonate is simple (Díaz-Canel Bermúdez *et al*., 2020) while the nitrite needs a hydroxyl scavenger to attain a high degradation yield (Bieri *et al*., 2017).

The achieved traces of metal ions in the understudied samples enhance the organic pollutants degradation depending on the catalytic effect (Glanville *et al*., 2017). The COD/BOD were preserved constantly before and after the management technique which was about 1.2 (Zeng *et al*., 2018). The using of gamma irradiation coupled advanced oxidation processes (AOPs) in the presence of HO. is highly viable for persistent organic pollutants' exclusion (Hoesly *et al*., 2018).

The radicals methoxy ($.CH_3O$), hydroxyalkyl ($.CH_2OH$), hydrogen (.H), superoxide anions (.O2), and peroxyl (.OOH) as well as the hydroxyl ion (OH) are created as a result of gamma radiation combined with ozonation (Qureshi *et al*., 2018), have a strong antimicrobial effect (Simone-Finstrom *et al*. Based on the previously indicated data, the Rotavirus has been rendered inactive (using a fast test), whereas the bacterial colony counts have dropped. Some anions that are found in water as contaminants, such as sulfate, speed up the breakdown of organic materials and increase the production of HO. (Chen *et al*., 2015):

$SO_4^- + HO^- \rightarrow SO_4^{-} + HO.\ K = 6.5 \times 107\ M^{-1}\ S^{-1}$ (1)

As the results of organics concentration reduction and the management of their derivatives such as turbidity, COD, and BOD highly purified water has resulted. The obtained water can be used safely for drinking and medical purposes.

Triclosan Degradation Using Typical Proposed Irradiation Conditions

The degradation of TC is carried out drastically using gamma irradiation under reduction conditions (by adding a hydroxyl scavenger). The addition of ethanol as a hydroxyl scavenger has a very efficient role in organic degradation and especially TC ((Rastogi *et al*., 2020), (Schmeling & Wagner, 2019). (Wu *et al*., 2020) reported that the reaction rate constant of ethanol with hydroxyl radical was 109 $M^{-1}\ s^{-1}$. By increasing the radiation dose, the TC degradation is increased up to 30 kGy as shown in Figure 1. With further radiation dose increased more or less degradation has been. There is a nearly negligible decrease in the degradation yield by increasing the TC concentration from 10 to 50 PPM.

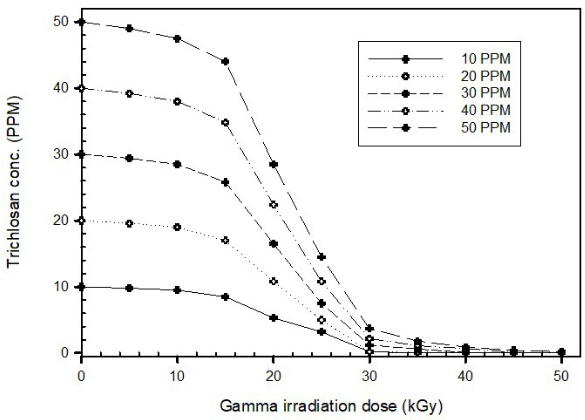

Figure 2: Degradation of different TC concentrations at different gamma irradiation doses, coupled with a hydroxyl scavenger (ethanol)

The difference in TC reached 66% in the presence of a hydroxyl scavenger (under reduction conditions). The complete TC degradation has been achieved by using extra10 kGy gamma irradiation coupled ozonation as seen in Figure 2.

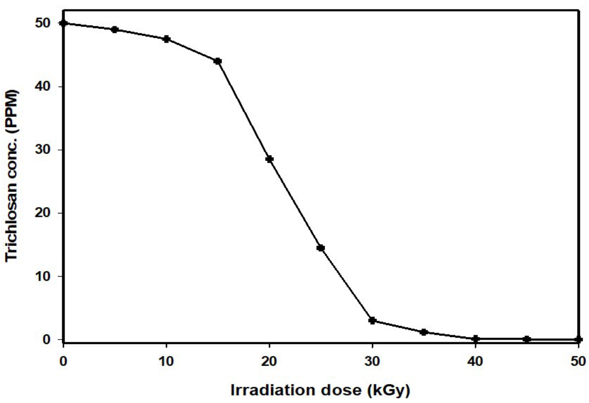

Figure 3: Degradation of 50 PPM of triclosan at different gamma irradiation doses under reduction and oxidation conditions

Numerous intermediate products were created by TC's gamma irradiation, and as a result, their molecular structures were determined. The TC's breakdown route is shown in Figure 3 for both reduction and oxidation situations. The gamma irradiation under the reduction condition of TC emerging chlorophenol and dichlorophenol have been produced. Through the starting 10 kGy, hydroxylation is a predominant process followed by dehydroxylation and dechlorination up to 30 kGy (Schmeling & Wagner, 2019). (Wang *et al.*, 2017) attempted to transfer electrons through carbon-centered radicals in the benzene ring, which resulted in the benzene ring's hydroxylation. This process is attributed to electron transfer via the O.

The gamma irradiation under oxidation conditions of the TC showed the dechlorination and dihydroxylation as basic processes. (Kurutach *et al.*, 2018) explain the formation of hydroxyl radicals by an electron transfer induced by the oxidation of water molecules. Finally, oxidation of the TC and their derivatives under gamma irradiation coupled with ozonation created environmentally friendly carbon dioxide and water (Théry *et al.*, 2018).

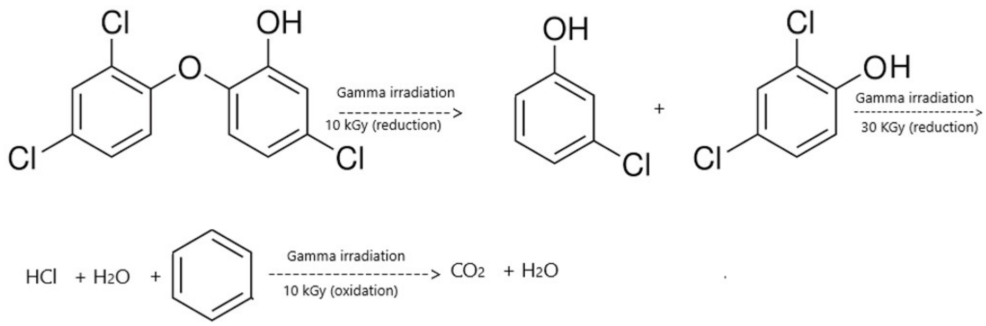

Figure 4: Scheme of triclosan degradation using gamma irradiation under reduction and oxidation conditions

Gamma irradiation has been used to control some significant variables like pH, TOC, and COD. At 10, 20, 30, and 40 kGy, the pH of the gamma-irradiated TC solutions decreases from 6.4, 6.1, 5.9, 5.7, and 5.5. According to (Xiao *et al.*, 2017), the creation of organic acids during the irradiation process explains how the results were reached. The understudied samples received identical irradiation dosages, which caused the TOC to fall to 3.3, 2.8, 2.5, 2.2, and 1.8 mg/L, respectively. As shown in Figure 4, the chemical oxygen demand (COD) increased gradually up to 30 kGy of irradiation before rapidly declining up to 40 kGy.

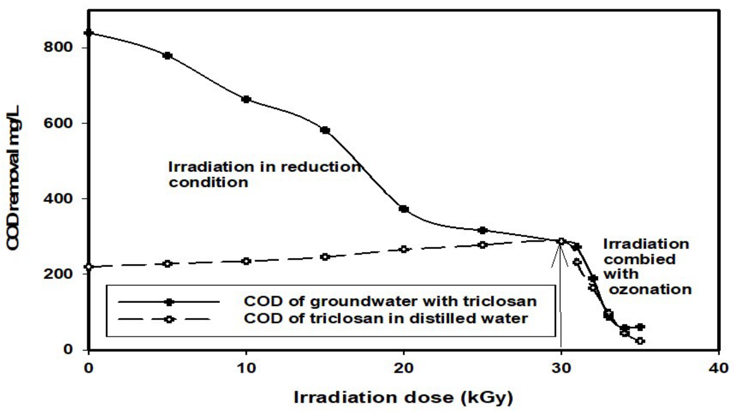

Figure 5: Management of COD (mg/L) under reduction and oxidation conditions at various irradiation doses

By irradiating the understudied wastewater that was contaminated with TC, the emerging TC's derivatives induced rising COD values with a modest cap. The resultant compounds, like dichlorofenol and chlorophenol, pose a greater threat to life than pure TC. The understudied samples were exposed to 40 kGy of coupled ozonation by increasing the gamma irradiations, and the COD decreased to acceptable levels because of the entire TC degradation to CO_2 and H_2O.

Gamma Irradiation Induced Metal Ions Exclusion

Many factors, conditions, and reasons strongly affect the reduction of metal ions and finally, precipitate them out of the understudied sample's solution. The availability of riding of the understudied metal ions may be due to a strong affinity towards the reaction with the understudied metal ions (Hg^{2+}, Cd^{2+}, and Pb^{2+}). The power of the gamma radiation affinity towards the metal ions is differentiated as the following; $Cd^{2} < Hg^{2+} < Pb^{2+}$. Based on this reason, the precipitation yield was 98%, 95%, and 94% for Cd^{2+}, Hg^{2+}, and Pb^{2+} respectively. Such atomic weight, ionic radii, and ionic charges are the factors influencing the radiation-precipitation process (Van Tran *et al.*, 2017). The real groundwater has behaviors similar to the understudied simulated wastewater polluted with metal ions according to their precipitation. The real groundwater has less affinity towards gamma irradiation may be due to many interferences pollutants that push fewer precipitation yields (Guy Jr *et al.*, 2017).

Upon water radiolysis, oxidation, and reduction species have been produced. e^{-}_{aq}, H., and H_2 were applied as reduction indices, while H_2O_2, H_3O^+, and HO. considered as oxidization species. The ratios of oxidation and reduction radicals originating from radiation can be summarized as the following:

$$H_2O \rightarrow [2.8]\ HO. + [2.7]\ e^{-}_{aq} + [0.6]\ H. + [0.72]\ H_2O_2 + [2.7]\ H_3O^+ + [0.45]\ H_2 \quad (2)$$

The understudied metal ions have two pathways oxidation and reduction directions. To compel the metal ions to go through the radiation-reduction reaction, the addition of an OH scavenger has been performed ((Deogaonkar *et al.*, 2019); (Ashfaq *et al.*, 2020).

Metal ions like Pb2+, Cd2+, and Hg2+ can be decreased quickly. According to (Sakanashi & Fujita, 2017), the reduction mechanism of the metal ions in the presence of e-aq is as follows:

$$M^{2+} + e^{-}_{aq} \rightarrow M^{+} \quad (3)$$

While the attained M+ undergoes disproportionation as the following:

$$2M^{+} \rightarrow M + M^{2+} \quad (4)$$

The intermediate product (MH+), which ultimately dissociates into a metal atom (M), makes the M^+ more available to react with H than the M2+. This pathway allows the M++ (Cd++, Pb++, and Hg++) to pass through the M+ state and reach the metal atom.

$$H + M^{+} \rightarrow MH^{+} \quad (5)$$

$$2MH^{+} \rightarrow M + H_2 + M^{2+} \quad (6)$$

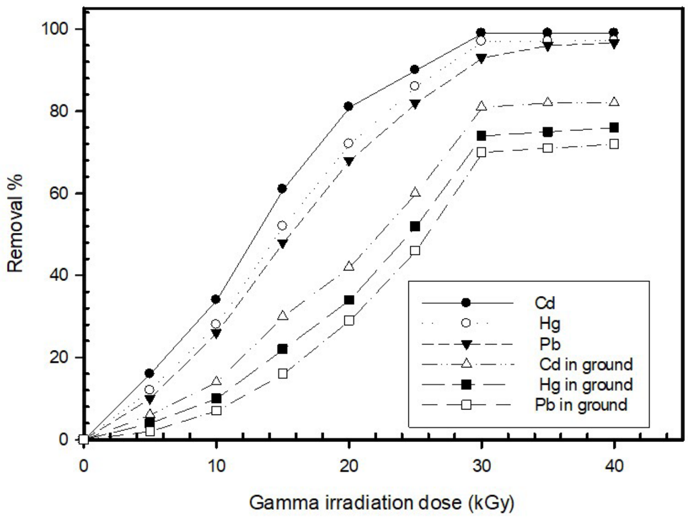

Figure 6: Effect of gamma irradiation on the precipitation of metal ions (Cd^{2+}, Hg^{2+}, and Pb^{2+}) for lab and groundwater samples

Table 2: Effect of gamma irradiation coupled ozonation on groundwater purification

No.	Irradiation treatment	Turbidity NTU	TDS mg/L	COD ppm	BOD ppm	TOC µM	Bacterial colony counting CFU/100ml	Rotavirus Rapid test
1-	Before treatment	7.2	870	840	380	75	1050	Positive
2-	30 kGy irradiation and hydrogenation	1.4	180	210	96	2.8	22	Negative
3-	5 kGy irradiation and ozonation	0.8	48	112	51	1.8	< 10	Negative

The Impact of Gamma Irradiation with De-Aeration and Hydroxyl Scavenging on the Riding of Understudied Metal Ions in Water

The Addition of Hydroxyl Scavengers to the Water Samples

Table (2) studied the addition of different aliphatic alcohols such as hydroxyl scavengers. For this purpose, methanol, ethanol, and isopropanol with 0.05% of volume concerning water samples were added for the elimination of the studied metals.

The addition of hydroxyl scavengers directed the reaction towards the reduction reaction pathway and avoided the metals ions oxidation with different states as in the following (Sato *et al.*, 2017):

$$.OH + M^{n+} \rightarrow M^{(n+1)+} + {}^{-}OH \quad (7)$$

The following reaction can be used to describe how aliphatic alcohols (hydroxyl scavengers) like methanol, ethanol, and isopropanol work (Dana *et al.*, 2020):

$$RCH_2OH + .OH \rightarrow R.CHOH + H_2O, \quad (8)$$

Metal ions (M^{2+}) reacted with the resulting R. CHOH species, as in the following:

$2R.CHOH + M^{++} \rightarrow 2(MR.CHOH)^+$ (9)

The reaction that dissociates the emerging (MR. CHOH) + into a precipitated metal form is as follows:

$(MR.CHOH)^+ \rightarrow M + H^+ + RCHO$ (10)

By investigation of different aliphatic alcohols, it is found that Methanol < ethanol < isopropanol in the efficiency as a hydroxyl scavenger. The methanol pushes to achieve exclusion yields of Cd^{2+}, Hg^{2+}, and Pb^{2+} to 99%, 97%, and 96% respectively. Ethanol represents less effective for OH scavenging than methanol while isopropanol was the least effective. Although ethanol has dangerous power on human health, it is considered the safest for human consumption in comparison to the rest of alcohol. The alcohol efficiency's differentiation can be explained by the fact of the reactivity of alcohols is inversely proportional to the alkyl length. The interfered pollutants in groundwater conduct less reactivity of the understudied metal ions in comparison to that of lab scales (Zhou *et al*., 2017).

Gamma Irradiation Coupled Gassing of Metal Ions

(Ferretti *et al*., 2018) postulate the role of gamma irradiation coupled de-aeration has an advantageous role in metal ions precipitation in comparison with aeration (Ferretti *et al*., 2018).

The oxygen and/or hydronium ions have an efficient role in the re-oxidation of precipitated metal form to a solvated metal ion form as the following reaction:

$O_2 + M + H_3O^+ \rightarrow M^{n+} + 3OH^-$ (11)

Based on this pathway the elimination of oxygen is a very important factor to stabilize the precipitated metal atom form.

(Lehmler *et al*., 2018) claimed that without de-aeration, the resulted in powerful oxidants O_2.-, and HO_2. emerged as a result of the reaction of dissolved O_2 with hydrated electrons and hydrogen atoms.

Table (2) showed the role of gassing coupled gamma irradiation in the metal ions precipitation. H_2 and N_2 have been studied for their role in purging oxygen upon gamma irradiation. In this manner the H_2 has double roles, the first elimination of oxygen while the second is the facilitation of metal ions reduction as explained in equations 5 and 6. The gassing of N_2 is less efficient in reduction reaction as it has solely role in O_2 expelling out of the samples.

CONCLUSION

To obtain extremely pure water that can be successfully used in medicinal applications and used as drinking water for the elderly, newborns, and sensitive people. Gamma irradiation has proven to be an effective method for controlling a variety of contaminants in groundwater. The management of several effects, including turbidity, TDS, COD, BOD, TOC, and the disinfection of water from bacteria and Rotavirus, is pushed by the strong role that gamma irradiation coupled with ozonation plays in organic degradation. Di- and chlorophenols developed during the TC degradation at 10 kGy, and de-chlorination and dehydroxylation were carried out at 30 kGy.

When TC reached 40 kGy, it finally totally broke down into carbon dioxide and water. By irradiating the water with gamma radiation in conjunction with reduction agents (such as hydroxyl scavengers and de-aeration), solvated metal ions that were once soluble in the water were converted to insoluble metals. At the best-understudied conditions, the final yield of metal ions (Hg++, Cd++, and Pb++) following the treatment was over 97%. These methods have successfully been used to purify groundwater and can be applied in a way that is safe for human consumption.

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