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The Relationship Between Environmental Abundant Electromagnetic Fields and Packaging Shape to their Effects on the Keeping Quality of Drinking Water

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An investigation studying the effects of EMF shielding, storage duration and packaging shape on the quality of natural mineral drinking water has been completed. Two identical groups each consisted of four containers with different packaging shapes were manufactured. The containers were used to store natural mineral water for 30 days at ambient room temperature (25°C). One group was shielded by applying Faraday's shield. The surrounding electromagnetic fields were measured during the storage period by using TS-EMF portable measurement system. During the storage period, samples were collected for analysis at the end of one week, two weeks and one month. The relationship between the containers' packaging shape and the electromagnetic fields to their effects on the physicochemical and microbiological parameters of water were explored by electromagnetic (EM) simulation. The physicochemical parameters of the stored water remained within the permissible guidelines of the World Health Organization. It was observed that variations in the HPC of the water samples stored both shielded and unshielded containers during the storage period. There was no coliform count detected in the stored water in the three trials during the three phases of the study period.The EM simulation showed variations in the total SAR and maximum point SAR values, which is the energy absorbed by water at 2,400 MHz for both vertical and horizontal polarizations. It can be concluded that the variations in the values of SAR induced in water are directly related to the variations in the physicochemical and microbiological parameters of the stored water.

Key words: Packaging shape, EM Simulation, water quality, shape effect, Coliform.

During the last few years, the world has witnessed a global shortage of drinking water. According to an estimate, more than 450 million people from 29 countries are directly affected by this global shortage of drinking water[1]. The unacceptable taste of the tap water, consumer safety concerns, and increasing awareness about the role of water in fitness and health reinforce the prospects of flourishing business for the bottled water industry. Besides the perception of taste, the massive growth of the bottled water industry has been sustained by the belief of the consumers that bottled water is safe compared to the tap water[2]. As a result, the demand for packaged drinking water has risen to unprecedented levels. The supply and maintenance of clean drinking water

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have become the most urgent concern amid global shortage[3]. The supply of safe drinking water for the residents has been incorporated into the national plans of almost every developing nation. As far as developed nations are concerned, many models for a safe drinking water supply have already been tested and successfully established. Unfortunately, these technologies for safe drinking water or the established models of water supply in the developed countries are not suitable for developing countries due to the social and technical cost of purification, entirely different functional public institutions, lack of technology, and political will to implement those models.

Many observations and study reports have produced documented evidence that counts of coliforms in these bottled waters exceeded national and international standards[4]. The study by[5] that reported on the bacteriological contamination of bottled water revealed that bottled water from various manufacturers included bacterial counts. There are many factors that cause deterioration of water quality and the contamination of bottled water. The quality of the bottled water entirely depends upon the efficiency of disinfection and the water treatment process. The redundant disinfection practices, insufficient treatment processes, and inadequate control of the entire process for any reason, including lack of properly trained staff, leads to the contamination of bottled water[6]. A study on the effect of storage duration and location on the microbiological quality of bottled water revealed that the heterotrophic plate counts (HPCs) for containers stored on a porch and car trunk were higher than HPCs for containers stored in indoor cabinets and refrigerators, respectively[7].

Recently, many studies have been conducted on the effects of the enhanced energy fields generated inside some geometrical shapes on biological materials and animals such as water, milk and rats[8-13]. The recent electromagnetic simulation studies[14-16] that were based on[17] that explained the source and the mechanisms of these effects showed scientific evidence. The studies were conducted to investigate the relationship between packaging shape of water containers and environmental abundant EM fields emitted from EM sources such as, Wi-Fi, cell tower, wireless laptop cards, to their effects on the stored water[15,16]. The studies showed that, the packaging shape of the containers caused a significant variations in the distribution and peak levels of electric and magnetic fields and specific absorption rate SAR values induced in the stored water[14, 15]. It was shown that, the peak levels of SAR values induced in the stored water are in the range of the SAR values that reported in the bioinitiative report 2012[16], which cause notable biological effects. SAR is a measure of the rate at which energy is absorbed by the biological material, such as water, when exposed to a radio frequency (RF) electromagnetic field, and it is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg)[19]. The exposure of drinking water to environmentally abundant electromagnetic fields during storage and the role of water as a universal solvent and living environment for microorganisms urge the researchers to study the relationship between environmentally abundant electromagnetic fields and packaging shape, to determine its effects on the microbiological and physicochemical parameters of drinking water during storage.

This study aims to examine and evaluate the effects of various packaging shapes, electromagnetic shielding and storage duration on various quality parameters of natural mineral drinking water, such as total coliforms, pH, TDS, HPC and hardness, in addition to investigating the relationship between packaging shape, surrounding EM fields and the stored water to their effects on water quality parameters using the electromagnetic simulation. The significance of this study is based on two main factors. First, studying the effect of packaging shape on water quality parameters and its relationship to environmental abundant electromagnetic fields will help in obtaining parameters for storage and water packaging process optimization. Secondly, exploring the mechanism of packaging shape effects and its relationship to the environmental abundant EM fields works as a gateway for other researchers to study the relationship between packaging shape and EM fields to their effects on food, pharmaceutical, chemical and cosmetics as well as the other biological substances..

MATERIALS AND METHODS

Containers Manufacturing

Eight containers were manufactured from 3mm thick polymethyl methacrylate PMMA sheets using an advanced CNC laser cutting system according to the dimensions mentioned in the study[14] as shown in (Figure 1); holes of approximately 3 mm in diameter were made in each of these containers to allow for easy placement of water samples. A square base of 242.362 mm was used with a height of 155.10 mm for manufacturing the pyramid-shaped container. The volume of water in the pyramid shaped container was calculated by using the dimensions in Table 1 (a) to solve formula (1). The rectangular, square and cylindrical shaped containers were manufactured with the same volume by solving the formulas (2), (3) and (4), respectively. The internal dimensions of the four containers are shown in Table 1 (a). The internal surface of the containers was isolated by eight internal sachets with 0.02mm thickness made of high-density polyethylene HDPE layers for each of the containers.

$$V = a^2 \frac{h}{3} \quad ..(1)$$

$$V = whl \quad ...(2)$$

$$V = a^2 h \quad ...(3)$$

$$V = \pi r^2 h \quad ..(4)$$

Where π Pi, r Radius, a Base edge, w Width, h Height, l Length.

Fig. 1. Eight PMMA containers

Electromagnetic shielding

It is well known that the electromagnetic fields upon entering conducting regions is shown to decay exponentially with a characteristic distance[18], δ referred to as the skin depth effect where:

$$\delta = \sqrt{\frac{\rho}{\pi f \mu}} \quad ..(5)$$

Where ρ represents the resistivity of the conductor in Ω.m, f represents the frequency in Hertz and μ defines the absolute magnetic permeability of the conductor $(\mu) = \mu_0 \mu_r$ where μ_r the relative permeability of the conductor and μ_0 represents the permeability of free space $\mu_0 = 4\pi \times 10^{07}$ H/m.

Faraday shield was made using 3mm aluminum sheets to shield one group of containers to minimize the exposure of environmentally abundant electromagnetic fields. The skin depth equation (5) was used to calculate the thickness of aluminum sheets to ensure that Faraday shield can cover the detection range of the electromagnetic fields measurement system.

Measurements of electric field level in the storage room

It is possible to derive the essential features for RF measurement equipments as long as we can use the frequency selective system. Frequency selective systems extend the analysis beyond the limitations of a particular frequency, allowing for assessment of any possible RF fields created by an electromagnetic source. In this study, we used the TS-EMF portable measurement system by Rohde and Schwarz (R&S) that included a spectrum analyzer type FSH 4 equipped with isotropic sensor. Although R&S RFEX software provided settings management and data acquisition, the entire system was designed to be computer driven. The spectrum analyzer covers a wide range of frequencies ranging from 100 kHz to 3.6 GHz, capable of covering many sources of electromagnetic radiation, such as radio and TV broadcasting, GSM, CDMA, and UMTS bands of mobile communications, Bluetooth, and WLAN (802.11b). Only indoor locations were selected, and in situ measurement was carried out in the storage room. The results were exported daily from the RFEX software. The system was specifically designed to measure E-field strength or power density. The tri-axis antenna provided hassle-free measurements, independent from direction or polarization of the emitter. Measurements become a bit complicated with directional antennas, as they must be moved to cover different directions or polarization. The system allowed peak hold measurement, so this mode was applied.

Storage conditions

The eight shielded and unshielded containers were placed on a wooden table and stored in a single 4x6m room, at room temperature (22°-25°C) for one month. A distance of 40 cm was maintained between each container and 100 cm distance from the walls. The square bases of the rectangular, square and pyramidal containers were aligned in the same direction. The water samples were collected from each container at the end of one week, two weeks and one month during the storage period. Regardless of the samples collected, the water containers remained constant throughout the study.

Electrical properties measurement

In order to measure the dielectric properties of water, vector network analyzer [HP8720B] was used. The system was consisted of Agilent 85070E dielectric probe kit with an open-ended coaxial probe and related software. All the measurements and evaluation in this study were conducted at the room temperature of 22 - 25 °C and using the frequency in the range of 300 MHz to 3 GHz. Complete calibration of the system was done before conducting each measurement.

Electromagnetic simulation

In this study, (CST STUDIO SUITE, 2014) EM simulation software was used to solve EM field equations by applying the finite-difference time-domain (FDTD) method to explore the relationship between packaging shape and the EM fields and their effects on the distribution of electric and magnetic fields induced in water. The EM simulation used to calculate the specific absorption rate (SAR) of the EM fields induced in water in the four containers. Three-dimensional models of the unshielded four containers, filled 100 percent with water, were designed according to the dimensions in Table 1 (a). The electrical properties, such as dielectric constant and conductivity of the materials, are closely related to their capacitance and ability to store energy[21]. Therefore, in order to mimic the experiment, the measured electrical properties of water were used in the configuration of CST STUDIO SUITE 2014 software before running the simulation. Plane waves with both vertical and horizontal polarizations were used to excite each of the four containers. The highest value of the electric field strength recorded by TS-EMF measurement system was used as the amplitude of the plane waves. The values of azimuth angle (phi) and elevation angle theta (theta) of the incident plane waves, mentioned in the study of [15], related to the maximum total SAR values induced in the four container models were used in the configuration of CST STUDIO SUITE 2014 software to represent the worst exposure scenario. In order to truncate the computational region, a perfectly matched layer (PML) was used to represent the absorbing boundary.

Sampling

Giant Water, the commercial natural mineral water, was used during the three trials of the study. The natural mineral water was sourced from an underground source according to the manufacturer. The gallon-sized bottles of water by the brand being examined were represented by using 5.5 liters PET plastic containers mixed together in an aseptic 25L HDPE Lifestyle brand water tank. The water in 25L water tank were used to fill eight HDPE sachets that were 0.02 mm in thickness, fitted inside each of the transparent PMMA pyramidal, square, rectangular and cylindrical containers as an internal sachets. Three

Table 1 (a). Dimensions of the internal surface of PMMA containers

Model	Width (mm)	Depth (mm)	Radius (mm)	Height (mm)
Pyramid-shaped	230.059	230.059	-	150.227
Cylindrical-shaped	-	-	74	154
Rectangle-shaped	120	120	-	184
Square-shaped	144	144	-	128

phases were used to study the effect of EMF shielding, packaging shape and storage duration on the quality parameters of natural mineral drinking water. The phases included 7days of testing on the first phase followed by a second phase of 15days, and third phase of one month. The phases involved numerous microbiological and physicochemical analyses, such as HPC, total coliform, TDS, pH, and hardness. The analytical methods approved by the American Public Health Association [APHA] were used for evaluating the quality of stored water. Samples of water were aseptically collected and analyzed before filling the eight containers. This analysis aimed to evaluate the bacteriological and physicochemical parameters of drinking water. The water samples stored inside the eight containers were collected and analyzed at the end of the first and second week for phase one and phase two of this study and one month for the third phase.

Bacteriological Analysis

The bacteriological quality of water was analyzed by coliform and HPC enumeration of the water during the three phases. The samples of the stored water were analyzed immediately after collection. As per the standard methods specifications, the spread plate technique was used for enumerating HPC of water samples[22]. The low temperature and longer incubation create favorable conditions for the growth of water-based bacteria[23], and therefore, 20° to 28° lower temperatures and 5- to 7day incubation periods were used for analyzing the quality of water samples. The R2A agar was used in the bacteriological examinations because the low nutrient agar replicated almost the same environment found in natural mineral bottled water. Two duplicate agar plates were prepared by spreading a 1 ml sample from each of the stored containers and incubated for seven days at 28°C to finally count the colonies. The water samples from each container were replicated to analyze and enumerate HPC. Total coliform were measured by membrane filtration procedures with a differential medium described in APHA Methods 9222 B[24].

Physicochemical Analysis

The study included analytical techniques for determining the physicochemical properties of water samples stored in different water containers. Physicochemical parameters of the stored water were analyzed immediately after collection. Stored water samples were analyzed after one week, two weeks, and one month of storage. The pH was measured electrometrically using a combination electrode (glass plus reference electrode) and was calibrated against 3 buffers purchased commercially in accordance with APHA 4500-H+. Total dissolved solids were measured by filtering a known sample volume and evaporating to dryness at 180°C and weighing the residue in accordance with APHA 254°C. Hardness as $CaCO_3$ was determined by titrimetric methods by adding EDTA as titrant, and the calcium and magnesium were complexes; the results were expressed as mg/L in accordance with APHA 234°C.

Data Analyses

Means, standard deviations, multiple comparisons were calculated using SPSS (version 22.0 for Windows). One-way ANOVA was used to test for significance between water containers from each group.

RESULTS AND DISCUSSION

Electric field strength measurement

The EMF measurements were exported daily from RFEX software during the three trials of the study. The measurements showed variations in the electric field strength during the three trials of study. The mean of the highest values of electric field strength from the three trials was calculated. The 2400 MHz frequency which is related to Wi-Fi networks was selected to explore the relationship between packaging shape, biological material and electromagnetic waves. The highest values of electric field strength at 2400MHz were used in the configuration of (CST STUDIO SUITE 2014) EM simulation software to represent the worst exposure scenario. The mean of the maximum values of electric field strength during the study period at 900, 1800 and 2400 MHz are shown in Table 1 (b).

Table 1 (b). Electric-Field Strengths (V/m) for different RF Signals at the storage room

RF signal	Frequency band (MHz)	$E_{max.}$ (V/m)
GSM900	900	2.2
GSM1800	1800	2.4
Wi-Fi	2400	1.3

Material properties

The dielectric properties of natural mineral water at 300MHz-3GHz at 22-25°C were measured. The PMMA manufacturer was used as a reference for the properties of PMMA while[25] was used as a reference for the properties of wood as shown in Table1 (c).

Electromagnetic Simulation

The highest values of electric field strength at 2400 MHz shown in Table 1 (b)were used as the amplitude of the plane waves in the configuration of the CST STUDIO 2014EM simulation software to represent the worst exposure scenario. Plane wave excitation was used to excite the surfaces of the pyramidal, rectangular, cylindrical and square container models from only one side. According to[15], the elevation angles caused a significant effect on the values of electric and magnetic fields and total SAR induced in water compared to azimuth angles. Therefore, the azemuth angle was set to 0° while the elevation angle (θ) ranged from 0° to 100° with a step width of 20°. The (θ) angle of the highest value of the maximum total SAR induced in water in the four container models was used to calculate the maximum point SAR in water in the four containers.

The maximum values of total SAR induced in water for vertical and horizontal polarizations are shown in Figures 2 (a) and (b), respectively and summarized in Table 2 (a). The results showed a significant variations in the maximum total SAR values induced in water for both vertical and horizontal polarization. The results indicate that the total SAR values induced in water in pyramidal container model was the highest at theta angles 0°, 20°, 60°, 80° and 100° for vertical and horizontal polarizations; this was followed by square, rectangular and cylindrical container models. The

Table 1 (c). Material properties used in the EM simulation.

Material	Dielectric constant ε'	Relative permeability μ	loss tangent tan δ	electrical conductivity σ (S/m)	Mass Density ρ (Kg/m3)
PMMA[a]	3.6	1	0.02	0.02	1190
Water	76@2.4GHz	0.999991	0.131	-	1000
Wood	1.65	1	0.03	-	500

a.Polymethyl methacrylate (*PMMA*)

Table 2 (a). Maximum values of total SAR induced in water in pyramidal, cylindrical, rectangular and square models for vertical and horizontal polarizations at 2400 MHz with respect to θ angles

Model	Polarization	Total SAR(W/ kg)	Theta (θ)
Pyramidal	Vertical/ Horizontal	2.9113e-005/ 2.136e-005	100°/ 100°
Cylindrical	Vertical/ Horizontal	1.7228-005/ 1.4400e-005	40°/ 20°
Rectangular	Vertical/ Horizontal	2.0057e-005/ 1.5605e-005	40°/ 0°
Square	Vertical/ Horizontal	2.0263e-005/ 1.6809e-005	100°/ 0°

Table 2 (b). Maximum point SAR induced in water in pyramidal, cylindrical, rectangular and square models for vertical and horizontal polarizations at 2400 MHz

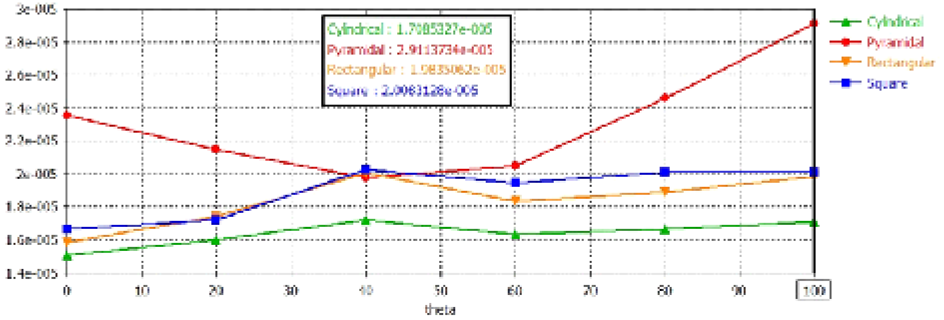
Model	Polarization	Maximum Point SAR(W/ kg)
Pyramidal	Vertical/ Horizontal	0.00112/ 0.001167
Cylindrical	Vertical/ Horizontal	0.227e-03/ 0.2347e-03
Rectangular	Vertical/ Horizontal	0.5024e-03/ 0.2708-03
Square	Vertical/ Horizontal	0.4151-e03/ 0.3759e-03

highest value of maximum total SAR was recorded at theta 100° for both vertical and horizontal polarizations. The highest value of maximum total SAR for square, rectangular and cylindrical models was recorded at 100°, 40° and 40° for vertical polarization and 0°, 0° and 20° for horizontal polarization, respectively. The maximum point SAR induced in water in the pyramidal, rectangular, square, and cylindrical models at 2,400 MHz for vertical and horizontal polarizations in different cross sections are shown in figures 3 (a) and (b), respectively and summarized in Table 2 (b). The maximum point SAR induced in water in the pyramidal container model was shown to be the highest for both vertical and horizontal polarizations followed by rectangular, square and cylindrical models for vertical polarization and square, rectangular and cylindrical for horizontal polarization.

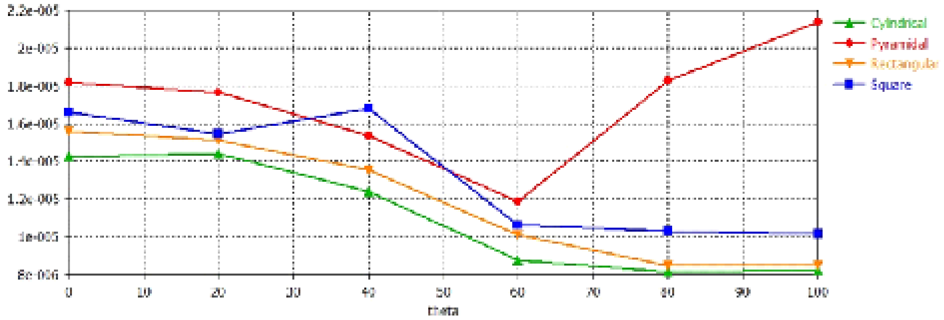
The results obtained from the electromagnetic simulation showed that, while the thickness, material properties of PMMA, wood and water in addition to the volume of water were identical in all container models, the variations in values and the distribution of total and maximum point SAR between all container models are directly related to the differences in the packaging shape and dimensions.

Physicochemical Quality of the Stored Water

The pre-storage mean value of pH value of the three trials of water stored in the shielded and unshielded containers was found to be (M = 7.750, SD=0.0500), as shown in descriptive analysis[1] and reached (M =7.733, SD=0.1155) and (M =7.600, SD=0.0000)[2] in EM shielded and unshielded groups at the end of the study period, respectively. The study revealed a significant difference in the mean of pH value [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, as well as the square and cylindrical containers in the three phases of the study period as shown in Post-Hoc analysis Tables 3-5. It was observed that the mean value of pH of all water samples decreased during the three phases of the storage period in the unshielded containers. There is no significant deference in the mean of pH value [$p < 0.05$] between water stored in the shielded pyramidal



(a)



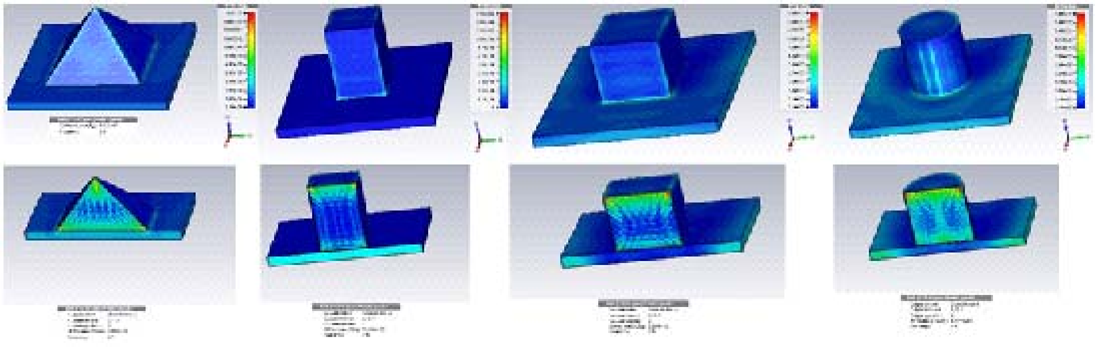
(b)

Fig. 2. Maximum values of total SAR induced in water in pyramidal, cylindrical, rectangular and square models for vertical (a) and horizontal (b) polarizations at 2400 MHz with respect to θ angles.

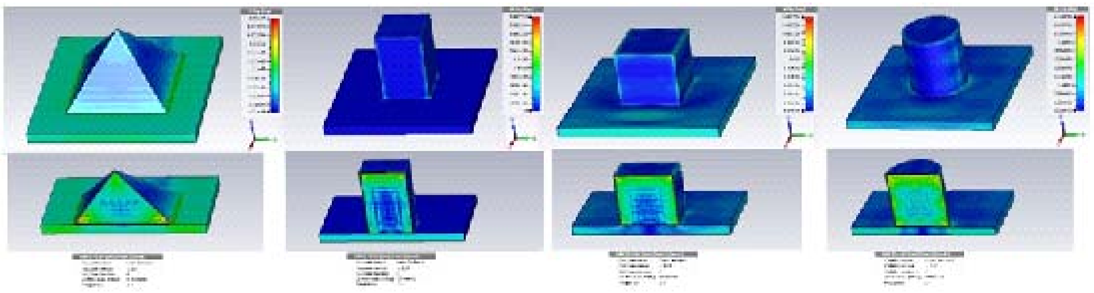
container and water stored in the shielded rectangular, square and cylindrical containers in the first and third phases of the study period as shown in Post-Hoc analysis[3]. The pH level of water significantly influence the aesthetic quality of drinking water[26]. The pH level of the medium is one of the main factors that determine the diversity and growth of bacterial colonies in stored water. In fact, some microorganisms produce acidic or basic metabolic wastes that help them to regulate the pH level of their habitat and frequently change the pH level of water[27].

The pre-storage mean value of TDS concentration of the three trials of water stored in the shielded and unshielded containers was found to be (M =74.00, SD=1.000) Mg/L, as shown in descriptive analysis[1] and reached (M =71.67, SD=0.577) and (M =68.00, SD=0.000)[2] Mg/L in EM shielded and unshielded groups at the end of the study period, respectively.The study showed no significant difference in the mean value of TDS concentration [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, square and cylindrical containers in the first phases of the study period, as shown in Post-Hoc analysis Table 3. There is a significant difference in the mean value of TDS concentration [$p < 0.05$] between water in the unshielded pyramidal container and water in the unshielded square container in the second phase, as shown in Post-Hoc analysis Table 4. This difference continues between water stored in pyramidal container and water stored in square and cylindrical containers in the third phase of the study period, as shown in Table 5. It was observed that the mean value of TDS concentration between all water samples decreased during the three phases of the storage period in the shielded and unshielded containers. Water stored in the unshielded pyramidal container showed the lowest mean value of TDS concentration in the three phases of study.

The pre-storage mean value of hardness of the three trials of water stored in the shielded and unshielded containers was found to be (M =64.00, SD=1.000) Mg/L, as shown in descriptive analysis[4] and reached (M =62.67, SD=0.577) and



(a)



(b)

Fig.3. Maximum point SAR distributions induced in water in pyramidal, rectangular, square and cylindrical models for vertical (a) and horizontal (b) polarization at 2400 MHz.

Table 3. Multiple Comparisons between water samples stored inside unshielded pyramidal, rectangular, cylindrical and square containers in terms of HPC, TDS, hardness and pH after one week of storage.

LSD Dependent Variable	(I)Container	(J)Container	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
HPC	Pyramidal	Rectangular	-733.333*	79.232	.000	-916.04	-550.62
		Square	-753.333*	79.232	.000	-936.04	-570.62
		Cylindrical	-990.000*	79.232	.000	-1172.71	-807.29
	Rectangular	Pyramidal	733.333*	79.232	.000	550.62	916.04
		Square	-20.000	79.232	.807	-202.71	162.71
		Cylindrical	-256.667*	79.232	.012	-439.38	-73.96
	Square	Pyramidal	753.333*	79.232	.000	570.62	936.04
		Rectangular	20.000	79.232	.807	-162.71	202.71
		Cylindrical	-236.667*	79.232	.017	-419.38	-53.96
	Cylindrical	Pyramidal	990.000*	79.232	.000	807.29	1172.71
		Rectangular	256.667*	79.232	.012	73.96	439.38
		Square	236.667*	79.232	.017	53.96	419.38
TDS	Pyramidal	Rectangular	-.667	.527	.242	-1.88	.55
		Square	-.333	.527	.545	-1.55	.88
		Cylindrical	-1.000	.527	.094	-2.22	.22
	Rectangular	Pyramidal	.667	.527	.242	-.55	1.88
		Square	.333	.527	.545	-.88	1.55
		Cylindrical	-.333	.527	.545	-1.55	.88
	Square	Pyramidal	.333	.527	.545	-.88	1.55
		Rectangular	-.333	.527	.545	-1.55	.88
		Cylindrical	-.667	.527	.242	-1.88	.55
	Cylindrical	Pyramidal	1.000	.527	.094	-.22	2.22
		Rectangular	.333	.527	.545	-.88	1.55
		Square	.667	.527	.242	-.55	1.88
HARDNESS	Pyramidal	Rectangular	-1.000	.577	.122	-2.33	.33
		Square	-1.333*	.577	.050	-2.66	.00
		Cylindrical	-2.000*	.577	.009	-3.33	-.67
	Rectangular	Pyramidal	1.000	.577	.122	-.33	2.33
		Square	-.333	.577	.580	-1.66	1.00
		Cylindrical	-1.000	.577	.122	-2.33	.33
	Square	Pyramidal	1.333*	.577	.050	.00	2.66
		Rectangular	.333	.577	.580	-1.00	1.66
		Cylindrical	-.667	.577	.282	-2.00	.66
	Cylindrical	Pyramidal	2.000*	.577	.009	.67	3.33
		Rectangular	1.000	.577	.122	-.33	2.33
		Square	.667	.577	.282	-.66	2.00
PH	Pyramidal	Rectangular	-.1000*	.0408	.040	-.194	-.006
		Square	-.2333*	.0408	.000	-.327	-.139
		Cylindrical	-.2667*	.0408	.000	-.361	-.173
	Rectangular	Pyramidal	.1000*	.0408	.040	.006	.194
		Square	-.1333*	.0408	.011	-.227	-.039
		Cylindrical	-.1667*	.0408	.004	-.261	-.073
	Square	Pyramidal	.2333*	.0408	.000	.139	.327
		Rectangular	.1333*	.0408	.011	.039	.227
		Cylindrical	-.0333	.0408	.438	-.127	.061
	Cylindrical	Pyramidal	.2667*	.0408	.000	.173	.361
		Rectangular	.1667*	.0408	.004	.073	.261
		Square	.0333	.0408	.438	-.061	.127

Table 4. Multiple Comparisons between water samples stored inside unshielded pyramidal, rectangular, cylindrical and square containers in terms of HPC, TDS, hardness and pH after two weeks of storage

LSD Dependent Variable	(I)Container	(J)Container	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
HPC	Pyramidal	Rectangular	-6876.667*	560.377	.000	-8168.90	-5584.44
		Square	-6636.667*	560.377	.000	-7928.90	-5344.44
		Cylindrical	-7956.667*	560.377	.000	-9248.90	-6664.44
	Rectangular	Pyramidal	6876.667*	560.377	.000	5584.44	8168.90
		Square	240.000	560.377	.680	-1052.23	1532.23
		Cylindrical	-1080.000	560.377	.090	-2372.23	212.23
	Square	Pyramidal	6636.667*	560.377	.000	5344.44	7928.90
		Rectangular	-240.000	560.377	.680	-1532.23	1052.23
		Cylindrical	-1320.000*	560.377	.046	-2612.23	-27.77
	Cylindrical	Pyramidal	7956.667*	560.377	.000	6664.44	9248.90
		Rectangular	1080.000	560.377	.090	-212.23	2372.23
		Square	1320.000*	560.377	.046	27.77	2612.23
TDS	Pyramidal	Rectangular	-.667	.577	.282	-2.00	.66
		Square	-1.667*	.577	.020	-3.00	-.34
		Cylindrical	-1.333*	.577	.050	-2.66	.00
	Rectangular	Pyramidal	.667	.577	.282	-.66	2.00
		Square	-1.000	.577	.122	-2.33	.33
		Cylindrical	-.667	.577	.282	-2.00	.66
	Square	Pyramidal	1.667*	.577	.020	.34	3.00
		Rectangular	1.000	.577	.122	-.33	2.33
		Cylindrical	.333	.577	.580	-1.00	1.66
	Cylindrical	Pyramidal	1.333*	.577	.050	.00	2.66
		Rectangular	.667	.577	.282	-.66	2.00
		Square	-.333	.577	.580	-1.66	1.00
HARDNESS	Pyramidal	Rectangular	-2.000*	.667	.017	-3.54	-.46
		Square	-2.667*	.667	.004	-4.20	-1.13
		Cylindrical	-3.667*	.667	.001	-5.20	-2.13
	Rectangular	Pyramidal	2.000*	.667	.017	.46	3.54
		Square	-.667	.667	.347	-2.20	.87
		Cylindrical	-1.667*	.667	.037	-3.20	-.13
	Square	Pyramidal	2.667*	.667	.004	1.13	4.20
		Rectangular	.667	.667	.347	-.87	2.20
		Cylindrical	-1.000	.667	.172	-2.54	.54
	Cylindrical	Pyramidal	3.667*	.667	.001	2.13	5.20
		Rectangular	1.667*	.667	.037	.13	3.20
		Square	1.000	.667	.172	-.54	2.54
PH	Pyramidal	Rectangular	-.2333*	.0333	.000	-.310	-.156
		Square	-.3000*	.0333	.000	-.377	-.223
		Cylindrical	-.3333*	.0333	.000	-.410	-.256
	Rectangular	Pyramidal	.2333*	.0333	.000	.156	.310
		Square	-.0667	.0333	.081	-.144	.010
		Cylindrical	-.1000*	.0333	.017	-.177	-.023
	Square	Pyramidal	.3000*	.0333	.000	.223	.377
		Rectangular	.0667	.0333	.081	-.010	.144
		Cylindrical	-.0333	.0333	.347	-.110	.044
	Cylindrical	Pyramidal	.3333*	.0333	.000	.256	.410
		Rectangular	.1000*	.0333	.017	.023	.177
		Square	.0333	.0333	.347	-.044	.110

Table 5. Multiple Comparisons between water samples stored inside unshielded pyramidal, rectangular, cylindrical and square containers in terms of HPC, TDS, hardness and pH after four weeks of storage

LSD Dependent Variable	(I)Container	(J)Container	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
HPC	Pyramidal	Rectangular	-55680.000*	1717.154	.000	-59639.76	-51720.24
		Square	-56516.667*	1717.154	.000	-60476.43	-52556.90
		Cylindrical	-60073.333*	1717.154	.000	-64033.10	-56113.57
	Rectangular	Pyramidal	55680.000*	1717.154	.000	51720.24	59639.76
		Square	-836.667	1717.154	.639	-4796.43	3123.10
		Cylindrical	-4393.333*	1717.154	.034	-8353.10	-433.57
	Square	Pyramidal	56516.667*	1717.154	.000	52556.90	60476.43
		Rectangular	836.667	1717.154	.639	-3123.10	4796.43
		Cylindrical	-3556.667	1717.154	.072	-7516.43	403.10
	Cylindrical	Pyramidal	60073.333*	1717.154	.000	56113.57	64033.10
		Rectangular	4393.333*	1717.154	.034	433.57	8353.10
		Square	3556.667	1717.154	.072	-403.10	7516.43
TDS	Pyramidal	Rectangular	-.667	.408	.141	-1.61	.27
		Square	-1.333*	.408	.011	-2.27	-.39
		Cylindrical	-1.000*	.408	.040	-1.94	-.06
	Rectangular	Pyramidal	.667	.408	.141	-.27	1.61
		Square	-.667	.408	.141	-1.61	.27
		Cylindrical	-.333	.408	.438	-1.27	.61
	Square	Pyramidal	1.333*	.408	.011	.39	2.27
		Rectangular	.667	.408	.141	-.27	1.61
		Cylindrical	.333	.408	.438	-.61	1.27
	Cylindrical	Pyramidal	1.000*	.408	.040	.06	1.94
		Rectangular	.333	.408	.438	-.61	1.27
		Square	-.333	.408	.438	-1.27	.61
HARDNESS	Pyramidal	Rectangular	-3.333*	.707	.002	-4.96	-1.70
		Square	-4.667*	.707	.000	-6.30	-3.04
		Cylindrical	-5.333*	.707	.000	-6.96	-3.70
	Rectangular	Pyramidal	3.333*	.707	.002	1.70	4.96
		Square	-1.333	.707	.096	-2.96	.30
		Cylindrical	-2.000*	.707	.022	-3.63	-.37
	Square	Pyramidal	4.667*	.707	.000	3.04	6.30
		Rectangular	1.333	.707	.096	-.30	2.96
		Cylindrical	-.667	.707	.373	-2.30	.96
	Cylindrical	Pyramidal	5.333*	.707	.000	3.70	6.96
		Rectangular	2.000*	.707	.022	.37	3.63
		Square	.667	.707	.373	-.96	2.30
PH	Pyramidal	Rectangular	-.4333*	.0236	.000	-.488	-.379
		Square	-.5000*	.0236	.000	-.554	-.446
		Cylindrical	-.5000*	.0236	.000	-.554	-.446
	Rectangular	Pyramidal	.4333*	.0236	.000	.379	.488
		Square	-.0667*	.0236	.022	-.121	-.012
		Cylindrical	-.0667*	.0236	.022	-.121	-.012
	Square	Pyramidal	.5000*	.0236	.000	.446	.554
		Rectangular	.0667*	.0236	.022	.012	.121
		Cylindrical	.0000	.0236	1.000	-.054	.054
	Cylindrical	Pyramidal	.5000*	.0236	.000	.446	.554
		Rectangular	.0667*	.0236	.022	.012	.121
		Square	.0000	.0236	1.000	-.054	.054

(M =61.33, SD=0.577)[5] Mg/L in EM shielded and unshielded groups at the end of the study period, respectively. The study revealed a significant difference in the mean value of hardness [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, square and cylindrical containers in the second and third phases as shown in Post-Hoc analysis Tables 4 and 5, respectively, and between water in pyramidal container and water in cylindrical container in the first phase of the study period, as shown in Table 3. There is no significant difference in the mean value of hardness [$p < 0.05$] between water stored in the shielded pyramidal container and water stored in the shielded rectangular, square and cylindrical containers in the first and second phases of the study, as shown in Post-Hoc analysis[4]. The mean value of hardness of all water samples decreased during the three phases of the storage period in the shielded and unshielded containers. Water stored in the unshielded pyramidal container showed the lowest mean value of hardness in the three phases of study. The hardness of water provides its palatability. The hardness of stored water has been analyzed according to WHO guidelines[28]. The total hardness of stored water was found within the WHO guidelines. The stored water belonged to the moderate soft water classification of the WHO.

Bacteriological Quality

The samples taken from all EM shielded and unshielded containers on the first phase showed bacterial re-growth, and subsequent growths tremendously increased during the three phases of the study period. The highest total heterotrophic bacteria regrowth was detected in water stored in the EM shielded containers. The mean value of pre-storage HPC count of water stored inside EM shielded and unshielded container groups was (M =145.00, SD=22.913), as shown in descriptive analysis[6] and reached the maximum of (M =202833.33, SD=3559.302) and (M =126720.00, SD=855.044)[7] at the end of the study period, respectively. The study revealed a significant deference in the mean value of HPC count [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, square and cylindrical containers in the three phases of the study period, as shown in Post-Hoc analysis Table 3-5, respectively.The mean value of HPC count of water stored in the unshielded pyramidal container was the lowest during the three phases of the storage period compared to the mean value of HPC count of water stored in the unshielded rectangular, square and cylindrical containers. Regarding the EM shielded containers, the study also showed a significant difference in HPC count [$p < 0.05$] between water in pyramidal container and water in rectangular, square and cylindrical containers in the first and last phases of the storage period, as shown in Post-Hoc analysis[5]. The HPC count of water in the EM shielded pyramidal container was lower than the HPC count of water in the EM shielded rectangular, square and cylindrical containers in the first and last phase of the study period. Regarding total coliforms count, the water samples stored in EM shielded and unshielded containers showed no presence of coliforms in the pre-storage examination, as well as the three phases of the study period. Although, the regulations of national primary drinking water that have been published by US Environmental Protection Agency regarding the potential health effects from long-term exposure to HPC above the maximum contaminant level MCL, stated that there is no health effects associated with HPC; it is an analytic technique for water used to measure the variety of bacteria[29]. The standards, objective and guidelines of drinking water published by Ontario Ministry of the Environment MOE stated that, the results of HPC in drinking water systems give an indication of the overall water quality. MOE also stated that the overall quality of the water should be monitored by the results of HPC and should not be used as an indicator of potential[30].

The EM simulation results of the four unshielded pyramidal, rectangular, square and cylindrical water container models showed that, , the order of the effect of EM fields on the total SAR values which is the energy absorbed by water is cylindrical < rectangular < square < pyramidal model at 2,400 MHz for both vertical and horizontal polarizations. The order of the mean value of HPC count of the three trials of the three phases of the storage period in the shielded and unshielded groups of containers is cylindrical<square < rectangular <pyramidal, except in the second phase of the unshielded container group which was cylindrical < rectangular < square < pyramidal. The highest values of maximum point SAR induced in water in the unshielded group of containers are in the range of the SAR values that reported in the bioinitiative report 2012[16], which cause notable biological effects such as the effects of SAR 0.00015–0.003 W/kg on calcium ion movement[31], 0.000021–0.0021 W/kg on cell proliferation[32], 0.0024–0.024 W/kg on DNA damage[33], 0.0035–0.001 W/kg on disrupting calcium metabolism[34], SAR 0.014 W/kg on fertility[35]. The microbial inactivation by nonthermal effects of EM fields was also highlighted by many reports[36-38]. A recent study showed that the variations in the values and distribution of electromagnetic energy induced in water stored in different packaging shapes have caused variations in the strength of hydrogen bonds between water molecules in H_2O-NaCl solution[14]. In addition, other studies have confirmed that the alignment of water molecules to non-thermal oscillating electromagnetic field within the microwave frequency range influences the strength of hydrogen bonds of water[39, 40]. The strength of hydrogen bonding play a crucial role in affecting the physical properties of water, ionization process and biomolecule hydration[41], which in turn can cause indirect effects on the physicochemical and microbiological parameters of water. The decrease in HPC count, pH, TDS concentration and hardness in the unshielded group of containers and the variations in HPC count in both shielded and unshielded groups and containers can be attributed to the variations in the distribution of SAR values induced in water as a result of the excitation of environmental abundant electromagnetic fields as explored by the electromagnetic simulation of the four water container models. The highest decrease in HPC, pH, TDS and hardness in the unshielded pyramidal container can also be attributed to the variation in the distribution of the highest values of total and maximum point SAR induced in the water compared to the values induced in the other unshielded containers as confirmed by the electromagnetic simulation. The reduction in the heterotrophic bacteria, pH value, TDS concentration and hardness is also exists in the EM shielded containers due to the limitation of Faraday shield, because it is shielding only a specific range of the EM spectrum based on the skin depth effect equation (5).

CONCLUSIONS

This research has studied the relationship between environmentally abundant electromagnetic fields, packaging shape and storage duration to determine their influence on the keeping quality of drinking mineral water by analyzing water quality parameters, such as pH, TDS, HPC and hardness. The electromagnetic simulation was used to explore this relationship. It has been observed that the physicochemical parameters of water remained within the permissible guidelines of the World Health Organization. There is a significant difference in HPC count and pH value [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, square and cylindrical containers in the three phases of the study period. There is a significant difference in TDS concentration [$p < 0.05$] between water in the unshielded pyramidal container and water in the unshielded square container in the second phase, and between water stored in pyramidal container and water stored in square and cylindrical containers in the third phase of the study period. The hardness of water showed a significant difference [$p < 0.05$] between water stored in the unshielded pyramidal container and water stored in the unshielded rectangular, square and cylindrical containers in the second and third phases, and between water in pyramidal container and water in cylindrical container in the first phase of the study period. There is no total coliform count detected in water in the pre-storage and the three phases of study period. The EM simulation showed that, the order of the effect of EM fields on the total SAR values which is the energy absorbed by water, is cylindrical<rectangular < square < pyramidal model at 2,400 MHz for both vertical and horizontal polarizations. It can be concluded that the variation in the values and distribution of SAR induced in the water in the four container models is a result of the change in the packaging shape of the containers that was exposed to the electromagnetic fields; this is indirectly affected the microbiological and physicochemical parameters of the stored water. In the future, it will be necessary to study the relationship between electromagnetic fields, packaging shape, and storage duration to determine their effects on water quality parameters by using different container size and longer storage periods.

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