



A Preliminary Study of the Leaching Effect of Phthalate Plasticizers in Sachet (Pure) Water Quality at Ambient Temperature

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ABSTRACT

Phthalate plasticizers have been widely used in the manufacture of sachet water in Nigeria. This study aims at analysing the leaching effects at room temperature on phthalate esters and their potentials to migrate from HPDE/PET packages to drinking water over a longer period of time so as to prevent or curb the harmful health conditions it can cause. Eight (8) 500 ml drinking water samples were kept on a table at the advanced research laboratory at the Environmental Management and Toxicology department of the Federal University of Petroleum Resources, Effurun, Delta State, for a period of eight weeks. The concentrations of phthalates (g/L) found in the brand of drinking water analysed after storage in ambient conditions for eight weeks were determined by gas chromatography-mass spectrometry (GC-MS). The limits of detection (LOD) and quantification (LOQ) were determined, as well as the accuracy (recovery study), precision (between-run and within-run), and linearity. The results showed that dimethylphthalate (DMP), benzylbutyl (BBP), and Di-n-octyl-phthalate were below the detection limits of the GC/MS utilized for the analysis (0.1 g per liter). The concentration of DMP, DEP, DBP, BBP, and DEHP increased significantly over the weeks of storage. Diethylphthalate recorded concentration of 0.53, 0.55, 1.16, and 2.49, in the first, second, fourth and eight weeks, respectively. Bis(2-ethylhexyl) phthalate was found to be the most prevalent Phthalates found in this research.

1. INTRODUCTION

Packaged drinking water is typically available in two forms, depending on the packaging material: (1) bottled water made of PolyEthylene Terephthalate (PET) and (2) sachet water made of High-Density Polyethylene (HDPE). Bottled water is usually packaged in plastic bottles, while HDPE sachet water is typically packaged in plastic sleeves. In addition to the short supply of drinking water, the production of high volumes of packaged water is a safety concern. Many people are of the opinion

that packaged water offers better bacteriological and physicochemical qualities, in comparison with corporation-supplied tap-water (Al-Saleh et al., 2011; Doria, 2006); however, research have proved that this may not be necessarily so. Several investigations have evaluated the microbial, physicochemical properties of bottled and sachet water and found them wholesome and fit for drinking (Danso-Boateng & Frimpong, 2013; Onweluzo & Akuagbazie, 2010), but some found the microbiological quality unacceptable

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(Fisher et al., 2015). It is known that some metals induce toxic effects in mammals, and they could be serious concerns threatening the safety of water supply. Furthermore, there is growing concern around the world that chemical components of packaging materials, particularly phthalate esters, will leach out of the matrix and contaminate the water inside the container. Dimethylphthalate (DMP), diethylphthalate (DEP), dibutylphthalate (DBP), di-n-hexyl-phthalate, and butyl benzyl phthalate have all been found in bottled and sachet water in varying concentrations (Kanchanamayoon et al., 2012; Keresztes et al., 2013; Edjere et al., 2016; Prapatpong & Kanchanamayoon, 2010). Meanwhile, the US Environmental Protection Agency (US EPA) has set DEP, DBP, and DMP limit values of 0.55, 0.45, and 5.0 mg/L, respectively (US EPA, 2012). The presence of emerging contaminants in drinking water, such as phenols (especially chlorinated and alkylphenols), plasticizers (particularly phthalates), PAHs, PFC, and PFOA/S, among others, may have major health repercussions for consumers (Abtahi et al., 2019; Akhbarizadeh et al., 2020). These toxins have been associated to adverse effects on human health such as cancer, reproductive problems, and endocrine disruption (Juberg, 2000; Michalowicz and Duda, 2007; Gavrilescu, 2009; Jugan et al., 2009; Essumang et al., 2012, 2013). The majority of them are harmful because they are resistant to degradation and are persistent organics that can bioaccumulate in tissues (Gavrilescu, 2009).

Packaged water is widely available in both wealthy and developing nations. Customers purchase bottled drinking water for a variety of reasons, including flavor, convenience, and fashion; nevertheless, safety and potential health benefits are also important considerations (WHO, 2017). Cans, laminated cartons, plastic or glass bottles, and plastic bags (sachets) are all common containers for packaging drinking water (WHO, 2017). In recent years, the

manufacturing of plastic bottled (sachet) water in Nigeria has more than doubled. In 2016, there were slightly more than 1600 registered sachet water production companies, however recent figures show slightly more than 3000 registered enterprises (Stoler et al., 2012; Odonkor, 2018). This means that the Ghanaian population's consumption habits have shifted toward sachet water rather than direct tap water. Phthalates are common emerging pollutants, and their presence in a variety of samples, including but not limited to soils, breast milk, water, food, and personal care products, has been reported in the literature (Schripp et al., 2010; Howdeshell et al., 2008; Toni, 2017; Adjei et al., 2019; Arfaenia et al., 2019; Dobaradaran et al., 2020; Moradian et al., 2020; Hung et al., 2021; Takdastan et al., 2021). Phthalates have reproductive toxicity, endocrine-disrupting properties, and teratogenic effect, adversely affecting the child's behaviour and intellectual motor development of the child (Benson, 2009; Kim et al., 2011; Suzuki et al., 2012; Bustamante-Montes et al., 2013; EC, 2014; Factor-Litvak et al., 2014; Ferguson et al., 2014; Bornehag et al., 2015; Swan et al., 2015; Muerkoster et al., 2020). The International Agency for Research on Cancer (IARC) listed bis(2-ethylhexyl) phthalate (DEHP) as a probable human carcinogen in its carcinogen monograph (IARC, 2012).

The study aims at analysing the leaching effects at room temperature on phthalate plasticizers in sachet water quality to prevent or curb the harmful health conditions it can cause.

2. MATERIALS AND METHODS

2.1 Sample Collection

A popular brand of PET sachet drinking table water was purchased from a table water factory (name withheld) located in Otokutu, Udu Local Government Area of Delta State on the day of production. The samples were purchased and collected from their factories on the day of production in

August 2021. Eight (8) 500 ml sachet of drinking water was kept on a table at the advanced research laboratory at the Environmental Management and Toxicology department of the Federal University of Petroleum Resources, Effurun, Delta state for a period of eight weeks. Temperature measurement for the study period ranged from 23 to 27 °C. A 500 ml sachet of drinking water was analysed after a week, two weeks, four and eight weeks of storage.

2.2 Chemicals and Reagents

Certified traceable EPA standards Phthalate Esters Mix: DMP (99.9%), DEP (99.9%), DBP (97.6%), BBP (98.7%), BEHP (99.7%) in hexane and Phthalate Esters Mix: DMP (99.9%), DEP (97.6%), DBP (99.3%), BBP (99.9%), BEHP (99.7%) in methanol were purchased from Sigma-Aldrich for recovery studies. Analytical grades Butyl benzoate (BB) and sodium chloride were purchased from BDH and Sigma-Aldrich, respectively. Dichloromethane and Methanol (both of which were HPLC grades) and analytical grade Hexane were purchased from Fisher Scientific (Loughborough, UK). Ultrapure water produced by a Milli-Q Integral water purification system (Millipore, USA) was used.

2.3 Preparation of Stock and Working Solutions

As working solutions, hexane was used to generate a stock solution of the Phthalate Esters Mix standards (40 g/mL) (DMP, DEP, DBP, BBP, and DEHP) and an internal standard (100 g/L) Butyl Benzoate (BB) from which further concentrations were prepared by serially dilution of the stock solution. Prior to use, all solutions were kept at 4°C in the dark.

2.4 Sample Extraction and Gas Chromatographic Analysis

A measured volume of water sample (0.5L), was weighed into a 0.5L calibrated Erlenmeyer flask (Bachema, 2021). To this, about 1ml Cyclohexane internal Standard solution was added then, 9ml of

cyclohexane was added (Bachema, 2021). An extract was derived from this mixture with the aid of a glass coated magnet for a minimum period of two hours. Using a special glass separating device, the solvent extract was isolated in a 10 ml vial (Bachema, 2021). The volume of the sample was 0.5L in 10 ml Cyclohexane extract (Bachema, 2021). A 0.5L aliquot of blank sample (Nanopure water) was prepared and extracted in a similar fashion as the water sample (Bachema, 2021).

The analytes in both the blank and sample derived extract were separated by capillary gas chromatography using temperature programming (Bachema, 2021). The chromatographically separated phthalate esters were then detected and measured with a Mass Spectrometer (Bachema, 2021). This process was made possible by large volume injection (LVI) method utilized to introduce 10µl of the sample solvent extract at a rate of approximately 4.6µl/sec into the injector (Bachema, 2021).

The injector was kept at an initial temperature of 78°C and gradually increased at the rate of 5°C/sec to 300°C so as to enable complete volatilisation of solvent into the analytical column (Bachema, 2021). Oven initial temperature was kept at 70°C and on injection increased to 300°C at a rate of 20°C/min. Injector's temperature was brought back quickly to normal by the use of a liquid Nitrogen Cryo cooling unit (Bachema, 2021). Phthalate separation and detection was conducted with the usage of a 30m BGB5 Column and a HP5973 mass spectrometer respectively. Analytical quantification was enabled with the usage of Agilent Chromstation software (Bachema, 2021).

2.5 Quality Control

All glassware was immersed in 10% nitric acid, then washed with detergent, rinsed with deionized water, dried, and sealed with aluminium foil before being stored. Glassware was also pre-rinsed with acetone before use. Separating funnels with Teflon stopcocks, glass vials and volumetric flasks with Teflon closures, and glass syringes

were utilized during sample handling. Plastic materials were not used at all. To check for possible contamination and interferences, laboratory reagents and instrumental blanks were analyzed with each batch of samples (5 samples) as a blank. The sensitivity of the GC-MS was evaluated for drift across batches of 5 samples using a midway calibration reference (4 ppm). To compensate for analyte loss during sample preparation, an internal standard was used. The drinking water samples were analyzed three times. The limits of detection (LOD) and quantification (LOQ) were determined, as well as the accuracy (recovery study), precision (between-run and within-run), and linearity. LOD and LOQ were determined as follows: $LOD = 3.3(Sy/S)$ and $LOQ = 10(Sy/S)$ (Shrivastava et al., 2011), where Sy is the standard deviation of the calibration curve's y-intercepts and S is the calibration curve's slope for concentration levels 1.0 - 8.0 g/L. To validate the results obtained for DMP, DEP, DBP, BBP, and DEHP, recovery tests were performed at concentration levels of 4.0, 6.0, and 10.0 g/L. A linearity study was also conducted, with five concentration levels and five repetitions. Five repeated analyses

of water spiked with DMP, DEP, DBP, BBP, and DEHP standards at concentrations of 1.0, 2.0, and 4.0 g/L were used to determine the method's precision (intra-assay), which was expressed as a percentage of relative standard deviation (%RSD).

2.6 Statistical Analysis

Microsoft Excel was used to calculate the mean, standard deviation, and variance of the different Phthalate concentrations from the GC-MS analysis.

3.0 RESULTS AND DISCUSSION

Recovery studies from spiked double distilled water (determined in triplicate) yielded means percentage recoveries of 88.3% for DMP, 78.5% for DEP, 90.3% for DBP, 91% for BBP and 86.5% for DEHP as shown in Table 1. Percentage recoveries in this study were lower than those obtained by Ekwealor et al., (2021) and similar to Kanchanamayoon et al. (2012). They had values of 87.3% for DBP and 79.17% for DEHP, while Fatoki et al. (2009), using SPE method, reported lower recoveries for DMP (82.14±1.32 %) and DEP (89.72 ±0.52 %) for water samples, than those obtained in this study.

Table 1: Results of recovery and spikes for phthalates in drinking water using GC-MS.

Sample Analytical and Instrumental Control		Expected PK	
Positive Control	Amount	Spiked PK value	60-140%
PKC	[µg/L]	Amount [µg/L]	Recovery [%]
Dimethylphthalate	4.416	5	88.3
Diethylphthalate	3.924	5	78.5
Dibutylphthalate	4.515	5	90.3
Benzylbutylphthalate	4.552	5	91
Bis(2-ethylhexyl)phthalate	4.323	5	86.5

The sachet water samples were analyzed for phthalates after placing the sachet water samples under ambient condition for a period of eight weeks. The results of the

analysis of Phthalate esters and their leaching in sachet water at ambient temperature for the full sampling period are presented in figure 1 below.

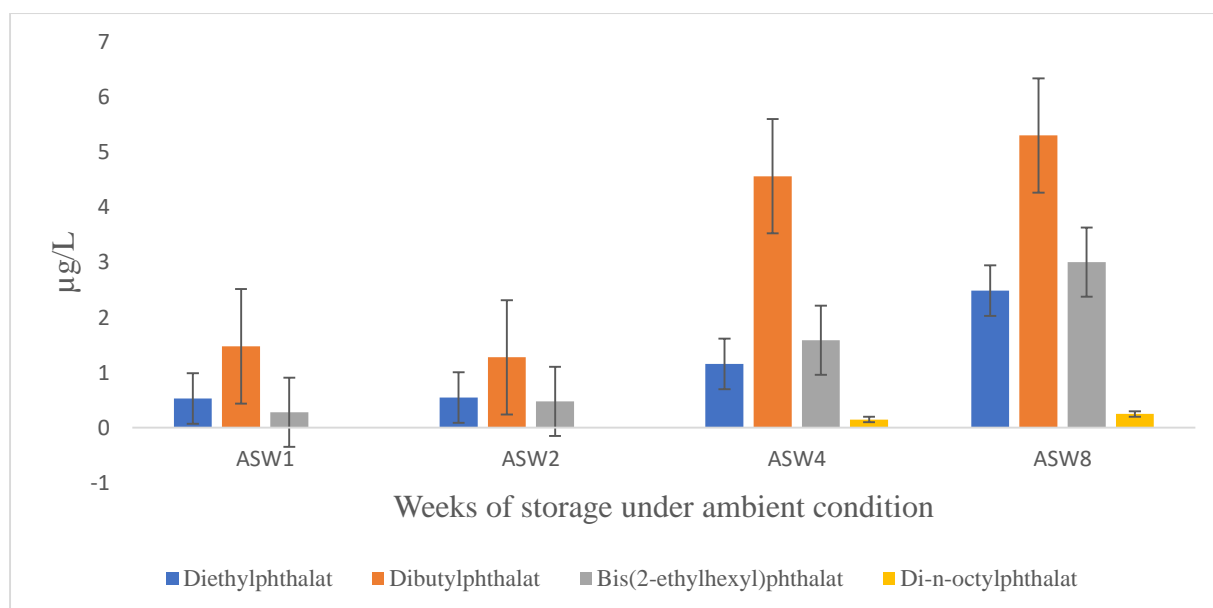


Figure 1: Concentration of phthalates ($\mu\text{g/L}$) found in the brand of sachet drinking water analysed after storage in ambient conditions for eight weeks.

*ASW = Ambient Storage at different weeks.

As shown in figure 1 above, For the eight (8) weeks of the study, dimethyl phthalate (DMP), and benzylbutyl phthalate (BBP), were below the detection limits of the GC-MS utilized for the analysis ($<0.1 \mu\text{g/L}$). Di-n-octylphthalate (DnOP) was below the detection limits of the equipment ($<0.1 \mu\text{g/L}$), in the first and second week of storage. However, in the fourth and eight weeks, the values were at 0.15 and $0.25 \mu\text{g/L}$ respectively. Three phthalate plasticizers, namely Dibutyl-phthalate, Diethyl-phthalate, and Bis(2-ethylhexyl)-phthalate showed significant, consistent phthalate concentration increase over the weeks of storage. Diethyl phthalate (DEP) recorded concentration of 0.53 , 0.55 , 1.16 , and $2.49 \mu\text{g/L}$ in the first, second, fourth and eight weeks of storage. Dibutyl phthalate (DBP) recorded concentration of 1.48 , 1.28 , 4.57 , and $5.31 \mu\text{g/L}$, in the first, second, fourth and eighth weeks of storage respectively. The concentration of Bis(2-ethylhexyl) phthalate (DEHP) increased from 0.28 in the first week to $3.01 \mu\text{g/L}$, in

the eighth week of storage.

The observed findings corroborated with the findings from Keresztes et al. (2009) who observed that phthalate dissolving rates increase with temperature. Temperature and contact surface area also influenced phthalate leaching, with higher contact surfaces between water and HPDE/PET packages translating to higher PAE concentrations, as demonstrated in the current study. Phthalate esters have been found to leach into food from HPDE/PET food packaging (Edjere et al., 2016). Sulentic et al., (2018) observed DBP in PET bottled water at concentration of 1.56 to $8.44 \mu\text{g/L}$ and the concentration of DEHP at 0.11 to $3.70 \mu\text{g/L}$ which were similar to was what recorded in this study. Dada et al., (2018) investigated the concentration of phthalates in sachet water and observed the concentration of DEP at 203 to 283 while the concentration of DBP was at 33 to $237 \mu\text{g/L}$. The results of Edjere et al., (2016) who analysed sachet drinking water in delta state using a GC-MS and determined

concentrations of DMP, DEP, DBP, BBP and DEHP in range of 0.04-0.095, 0.16-12.44, 0.56-3.38, not detected-0.03, and 0.08-0.31 µg/L respectively and were similar to the results from this study.

Also known as Endocrine disruptors, phthalate esters have been proven in tests to interfere with hormonal activity such as estrogen and thyroid hormones (Botelho et al., 2009 and Caporossi et al., 2020). DEHP, in instance, not only possesses the general property of PAEs, but in vivo and in vitro studies have connected DEHP or its metabolites to a number of negative effects in the liver, reproductive system, kidneys, lungs, and heart (Tickner et al., 2001). Except for DEHP, no phthalate values in drinking water are stated. The USEPA has defined the maximum acceptable limit (MAL) for DEHP in drinking water at 6 µg/L, while the European Union (EU), World Health Organization (WHO), and China have placed the MAL for DEHP in drinking water at 8 µg/L. (Ekwealor et al., 2021). When the DEHP values in this investigation were compared to the MALs, the maximum value obtained was greater than 6 µg/L but less than 8 µg/L. The most prevalent phthalate discovered in the drinking water samples was di (2-ethylhexyl) phthalate.

4. CONCLUSION

This study has successfully characterized and determined the presence of phthalate esters and their potentials to migrate from HDPE sachets to drinking water over a period during preservation, which can lead to possible health complications in humans. From the concentrations of phthalate esters increasing in concentration over a longer period of time, this study has revealed that sachets of drinking water kept in local kiosk or retail houses over a long period of time especially in Effurun and its environs pose

a serious health concern to consumers in the locality. Phthalates have been linked to a number of negative reproductive outcomes in both men and women, including type 2 diabetes and insulin resistance, obesity, allergy, and asthma (Wang et al., 2021). Phthalate Plasticizers are critical to the production of common food and consumable wrappers such as sachet water. The main objective of the study was the measure the prevalence and concentration of phthalate plasticizers in a selected brand of sachet drinking water in Effurun, Delta State. To regulate the amounts of Phthalate plasticizers utilized and keep them within acceptable limits, especially considering the recognized dangers associated with several of the Phthalate plasticizers discovered in this study, it is vital to monitor the following in the Delta State and the Nigerian sachet water industries: Diethyl phthalate, Dibutyl Phthalate, Bis(2-ethylhexyl) phthalate and Di-n-octyl phthalate. These Phthalate plasticizers have been demonstrated to be utilized in the manufacture of sachet water; their likelihood of use in similar items is high; therefore, their use in other industries or products must be monitored.

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