ORIGINAL ARTICLE

Trace Monitoring of Phthalate Esters in Environmental Water Samples by Ionic Liquid-based Ultrasound-assisted In-situ Solvent Formation Microextraction Combined with High-performance Liquid Chromatography

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ABSTRACT: A simple and efficient ionic liquid-based ultrasound-assisted in-situ solvent formation microextraction (IL-UA-ISFME) in combination with high-performance liquid chromatography-ultraviolet detection (HPLC-UV) has been gainfully developed for the trace determination of four phthalate esters (PEs) in environmental water samples. In this method, a hydrophobic ionic liquid (1-butyl-3-methylimidazolium hexafluorophosphate) was created by addition of a hydrophilic ionic liquid (1-butyl-3-methylimidazolium tetrafluoroborate) to sample solution constituting an ion-pairing agent ($NaPF_6$). The analytes were extracted inside the ionic liquid phase while the microextraction solvent was dispersed through the sample by utilizing ultrasonic radiation. The sample was then centrifuged and extracting phase retracted into the microsyringe, diluted with acetonitrile, and injected to HPLC. At first, vigorous parameters controlling the performance of the microextraction process were considered and optimized. The limit of detections (LOD, S/N = 3) were in the range of 0.22-0.33 µg L^{-1} while the RSD% values were below than 6.1% (*n* = 5). A good linearity ($0.996 \geq r^2 \geq 0.992$) and a broad linear over the concentration range from 1.0 to 500 µg L^{-1} were achieved. At last, the method was applied for the preconcentration and sensitive determination of the PEs in several environmental water samples. The accuracy of the method in the real samples was examined by the relative recovery experiments with results ranging from 90-107%, which approved that intricate matrixes had approximately slight effect on the developed procedure.

INTRODUCTION

Phthalate esters (PEs) are prominent polymer additives that are used in formulations of plastics, paints, pesticides and etc.; although, their main application is as plasticizers to enhance the workability and flexibility of polymeric materials [1, 2]. They are just physically, not chemically, bound to the polymer structures and they may be released into the environment during the production, use and disposal processes [3, 4]. Certain PEs as well as some of their degradation products and metabolites can cause toxic effects in human organs including kidneys, liver and lungs [5, 6]. The potential endocrine disrupting features of PEs possibly associated with their known estrogenic and anti-

androgenic activities have also been reported [7, 8]. Consequently, with the rapid development of the plastics industry at mega-scale, PEs have been becoming universal environmental contaminants which attracted great attentions worldwide.

High-performance liquid chromatography (HPLC) [9-11] and Gas chromatography (GC) [12-14] have frequently been conducted for the analysis of PEs in multitudinous media. Additionally, when the concentration levels are low, a prior enrichment step is normally demanded. The extraction techniques, which are routinely served ahead the instrumental analysis, are liquid-liquid extraction (LLE) [15, 16] and solid-phase extraction (SPE) [17, 18]. Nonetheless, these sample pretreatment methods desire either immense amount of sample and poisonous organic solvents though they are considered as time-consuming, labor-intensive and expensive with oftentimes result in strong blank values [19, 20]. With these mentality, a variety of microextraction techniques that use no or negligible amounts of solvent have been expanded in last years.

Ionic liquids (ILs) are non-molecular solvents with low melting points, trivial vapor pressures, and high thermal stability [21, 22]. Their privileged solvation features imparting ILs unique selectivity together with diverse separation mechanism, coupled to the fact that they can be structurally tailored for standalone applications [23, 24]. There have been ascended attentions for employing the physicochemical characteristics of ILs in diverse analytical chemistry purposes [25, 26].

Lately, Zeeb et al., has been designed a novel microextraction technique organized as a high performance and potent preconcentration method, viz. ionic liquid-based ultrasound-assisted in situ solvent formation microextraction (IL-UA-ISFME) [27, 28]. This strategy is based on the dissolution of a hydrophilic IL in an aqueous solution including objective analytes, followed by the addition of an ion-exchange reagent which undergoes an in-situ metathesis reaction forming an insoluble IL. Henceforth, analytes are extracted and preconcentrated immediately the IL is insolubilized whilst mass transfer process is speed-up meaningfully by ultrasound wave. This predominant and environmentally friendly method is an efficient and acceptable analytical procedure, for which fascinating accuracy and precision are confirmed, being easy and sensitive enough for the screening intentions.

The objective of present study is to examine IL-UA-ISFME technique aptness for the trace monitoring of selected four PEs in environmental water samples. The items affecting the microextraction efficiency were investigated in detail and the optimum conditions were fixed. After all, the method was endorsed for quantitative goals and utilized to real sample analysis in combination with high-performance liquid chromatography-ultraviolet detection (HPLC-UV).

MATERIALS AND METHODS

Chemicals

All PEs standards including dimethyl phthalate (DMP), diethyl phthalate (DEP), butylbenzyl phthalate (BBP) and dibutyl phthalate (DBP) (with purity of 98-99%) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Analytical grade of 1-butyl-3-methylimidazolium tetrafluoroborate [Bmim][BF$_4$], sodium hexafluorophosphate (NaPF$_6$), HCl and NaOH were obtained from Merck Company (Darmstadt, Germany). 1-hexyl-3-methylimidazolium tetrafluoroborate [Hmim][BF$_4$] was purchased from Fluka Company (Steinheim, Switzerland). HPLC grade of acetonitrile and methanol were purchased from Riedel-de Haën Company (Germany). Ultrapure water (Millipore, Bedford, MA, USA) was used for preparing standards and dilutions. All solutions were stored at 4°C and protected from light.

Apparatus

A HPLC system (Shimadzu, Kyoto, Japan) including a pump, an automatic injector equipped with 20 μL sample loop and a UV detector (set at 225 nm) was applied for the analysis of the PEs. The analytical column chosen for the separation was a RP-C$_{18}$ (LiChrospher, Merck Millipore, Darmstadt, Germany) with 10 μm particle size and dimensions of 250 mm × 4.6 mm i.d., at room temperature of 20 ± 0.5 $^\circ$C. Isocratic mobile phase consisted of acetonitrile and water (65:35, v/v) at a flow rate of 1.0 mL

min^{-1} was run through the column. A GS-6 centrifuge (Beckman, CA, USA) was utilized for accelerating the phase separation. The hydrophobic ionic liquid (as the extraction solvent) was dispersed through the aqueous media via Sonorex ultrasonic baths (Bandelin, Berlin, Germany). The mobile phase was filtered using a 0.2 μm membrane filter (Millipore, Bedford, MA, USA) and it was degassed continuously using an online degasser.

Preparation of solutions

A stock solution of four PEs at concentration level of 1.0 mg L^{-1} for each analyte was prepared in methanol. Working standard solutions were prepared by diluting the stock solution with water at known concentrations. A 1.0 g mL^{-1} solution of [Bmim][BF$_4$] as hydrophilic IL was prepared in methanol. A solution of 160 mg mL^{-1} of NaPF$_6$ as an ion-exchange reagent was obtained by dissolving required amount of this salt in ultra-pure water. All the stock and working solutions were stored at 4 $^\circ$C.

Real samples collection

The performance of the proposed method was evaluated by analyzing the PEs in four environmental water samples including: Caspian Sea (Amol, Iran), Persian Gulf (Bushehr, Iran), Jajroud River (Tehran, Iran) and Latian Dam (Tehran, Iran). The samples were collected in amber glass bottles (1000 mL). The bottles were rinsed several times with the water to be analyzed and filled till overflow to prevent loss of volatile organic compounds in the presence of the headspace. The water samples were filtered before the analysis using a 0.45 μm nylon membrane filter (Whatman, Maid-stone, UK) to eliminate the particles. All the samples were transported and stored at the refrigerator at 4 $^\circ$C until their analysis time.

IL-UA-ISFME procedure

In IL-UA-ISFME, 5.0 mL of sample solution was poured into a centrifuge tube with a conical bottom. Then, 0.5 mL of NaPF$_6$ (160 mg mL^{-1}) as an ion-exchange reagent was dissolved into the solution. To form water-immiscible [Bmim][PF$_6$] IL, 80 mg of water-miscible [Bmim][BF$_4$] IL was added to the aqueous sample solution. In order to disperse the hydrophobic IL through the sample, the test tube was transferred into an ultrasonic bath and sonicated for 5 min. Under this condition, the in-situ formed water-immiscible [Bmim][PF$_6$] IL was totally dispersed into the aqueous media and hence, the analytes were immediately extracted into the fine drops of [Bmim][PF$_6$] IL. To accelerate phase separation and moving IL to the bottom of the test tube, the sample solution was centrifuged for 4 min at 4000 rpm. The upper phase was decanted-off and the enriched phase (approximately 11.0 μL) was diluted with acetonitrile to a final volume of 25.0 μL and then injected into HPLC-UV. Schematic of the presented microextraction is shown in Figure 1.
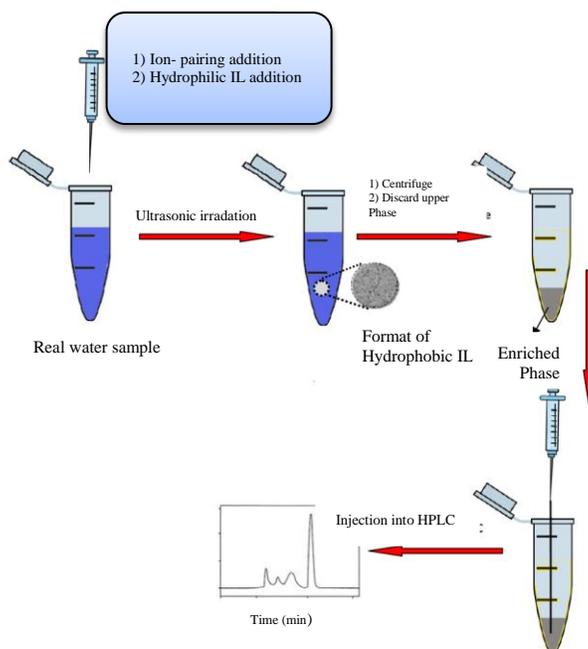
Figure 1. Schematic diagram of the proposed method for quantification of the PEs.

RESULTS AND DISCUSSION

A univariate method was used to optimize the influential parameters within this work. A fixed concentration of all PEs (50.0 μg L^{-1}) was performed in the optimization process. Quantifications were made by calculating the peak areas from the average of three replicate measurements while blanks were run periodically to confirm the absence of contaminations.

The selection of hydrophilic ionic liquid and ion-exchange reagent

In this enrichment method, an available, hydrophilic and cost-effective ionic liquid is added to the sample solution containing an ion paring agent in order to create a hydrophobic ionic liquid acting as extractor. For this goal some parameters regarding hydrophilic ionic liquid must be considered: (1) hydrophilic property of IL (2) density of the in situ formed hydrophobic IL (3) expense of IL (4) extraction capability of analyte of interest and (5) chromatographic behavior. In the case of hydrophilic property, the ILs containing Cl^-, BF_4^- and $CF_3SO_3^-$ are

water-miscible and ILs containing PF_6^- and $(CF_3SO_2)_2N^-$ are water-immiscible. It is reported that the ionic materials which include $(CF_3SO)_2N^-$ are not inepenesive and the cost of those materials which include BF_4^- are inexpensive [29]. So, 1-butyl-3-methylimidazolium tetrafluoroborate [Bmim][BF_4] and 1-hexyl-3-methylimidazolium tetrafluoroborate [Hmim][BF_4] ILs, which meet the mentioned requirements, were selected for optimization process. These ILs shows acceptable hydrophilic property, which is fitted with principles of ISFME, but in the case of [Hmim][BF_4] IL, the extraction recovery was lower in comparison with [Bmim][BF_4] IL. As a result, [Hmim][BF_4] was not selected for further consideration. As well the density of the generated extraction phase must be higher than water to make its collection at the bottom of the sample vial possible. Finally, to achieve a compromise between these points, 1-butyl-3-methylimidazolium tetrafluoroborate [Bmim][BF_4] IL was selected as an optimum hydrophilic IL. This ionic material was added to the sample media including ion paring agent ($NaPF_6$) to

generate 1-butyl-3-methylimidazolium hexafluorophosphate [Bmim][PF$_6$] acting as the extractor.

The effect of hydrophilic IL amount

The effect of [Bmim][BF$_4$] IL amount on the method performance was studied in range of 10-120 mg. As shown in Fig. 2, reproducible and sensitive signals were obtained using 80 mg of [Bmim][BF$_4$] IL. In this experiment, it was revealed that a growth in the dosage of [Bmim][BF$_4$] resulted a meaningful growth in the volume of the generated hydrophobic extractor decreasing the sensitivity of signals. As a result, a value of 80 mg was used for the rest of the experiments.
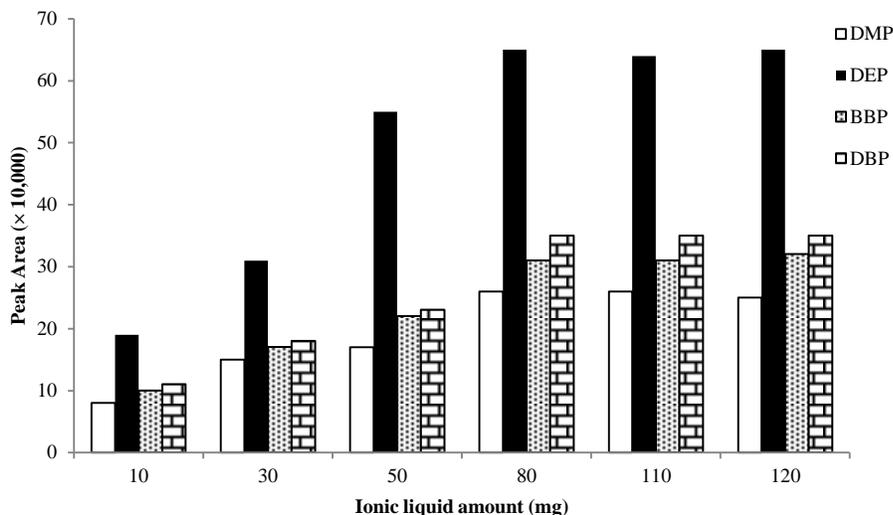

Figure 2. Influence of hydrophilic IL ([Bmim][BF$_4$]) amount on the extraction efficiency.

The effect of NaPF$_6$ amount

To form hydrophobic extractor, an excess dosage of NaPF$_6$ was dissolved in an aqueous media. The effect of NaPF$_6$ quantity was examined in the range of 30-140 mg. As it can be seen in Figure 3, with growing the amount of this reagent, the peak area boosts up to 80 mg and then, analytical signals get to steady conditions. As a result, to acquire a balance within sensitivity and reproducibility, 80 mg of this reagent was chosen as the optimum.
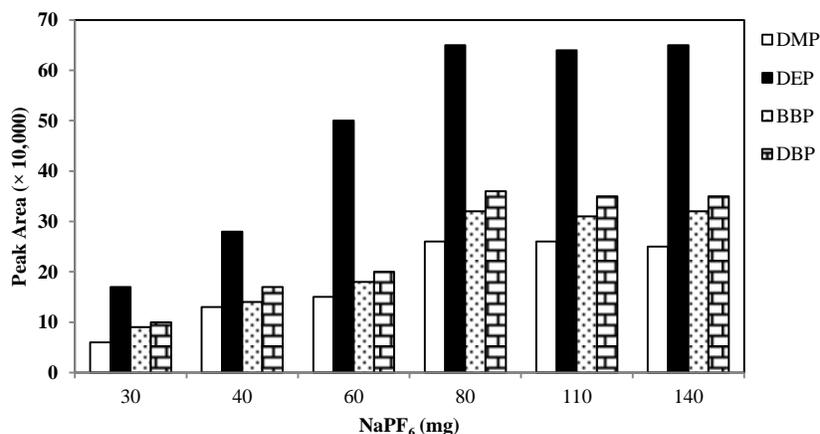

Figure 3. Effect of ion-pairing agent (NaPF$_6$) amount on the extraction performance.

The effect of salt addition

Due to salting out effect, addition a salt like NaCl causes a reasonable increase in ionic strength of sample media resulting an improvement in extraction performance [30]. For this aim, several concentrations (0%-25% w/v) of NaCl were added to the sample solution to investigate its effect on the extraction efficiency (Figure 4). This can be clarified by the evidence that by growing the viscosity of the sample solution, at higher concentrations of NaCl (> 15% w/v), diffusion of the analytes toward the extracting solvent becomes difficult. The maximum signal was achieved at the NaCl concentration of 15% w/v and noticed to decline afterwards. Accordingly, a fixed concentration of 15% w/v NaCl was used as the optimum value.
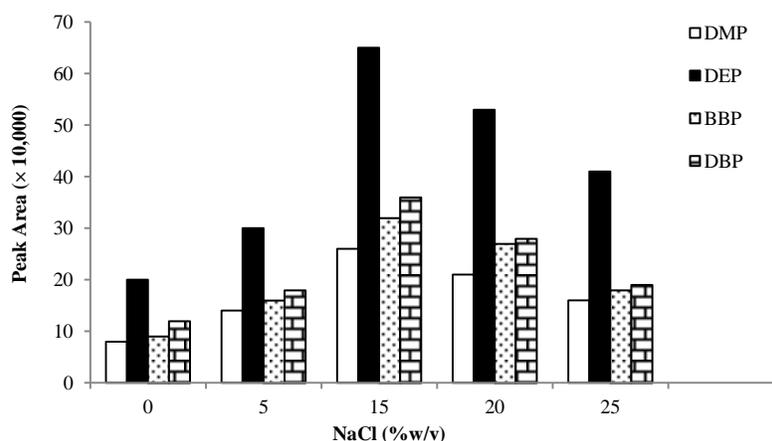

Figure 4. Impact of ionic strength on the extraction phenomenon.

The effect of sonication time

In this extraction strategy, in order to control mass transfer efficiency and obtain acceptable repeatability, it is needful to choose a suitable extraction time [31, 32]. To achieve the best extraction performance, applying ultrasonic irradiation is a reasonable plan to enhance the enrichment efficiency and speed up the extraction of target analytes into droplet of extraction solvent. Herein, the sonication time profiles were investigated in the range of 1-15 min at the power of 50 W. As shown in Figure 5, by increasing the values up to 5 min, the extraction efficiencies rose rapidly and afterwards remained relatively constant. It is noteworthy that longer extraction time can result in the loss of the extracting solvent and contraction of the extraction yields. Consequently, the exposure time of 5 min was selected as optimum value in the subsequent experiments.
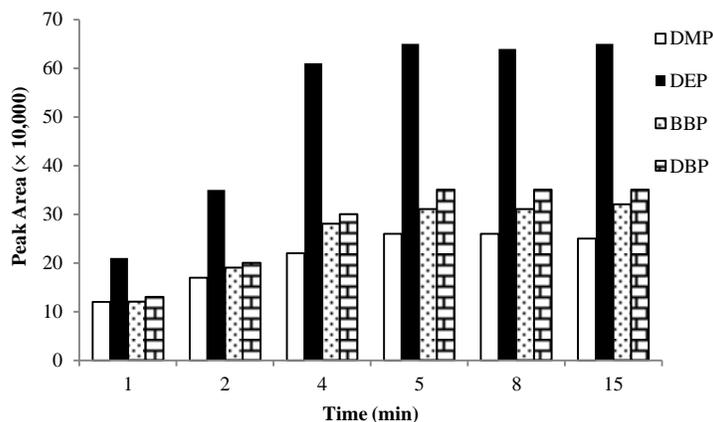

Figure 5. Ultrasonic irradiation time profile on the extraction yield.

The analytical performance

To ascertain the applicability of the method, calibration curves were plotted at the optimum conditions using spiked levels of the analytes. The limits of detection (LODs) based on the signal-to-noise ratio (S/N) of 3, the determination coefficients (r^2), the linear ranges (LRs) and the relative standard deviations (RSDs) were calculated and summarized in Table 1. As shown in Table 1, LODs were in the range of 0.22-0.33 µg L^{-1} and LOQs were in the range of 0.72-0.93 µg L^{-1} while linearity values varied in the range of 1.0 to 500 µg L^{-1} with correlation coefficient of 0.992 to 0.996. The precision of the method was investigated with 50.0 µg L^{-1} PEs mixed standard solution and the RSDs for six replicate measurements varied from 4.8 to 6.1%.

Table 1. Some quantitative data achieved by using IL-UA-ISFME and HPLC-UV for the determination of the selected PEs.

Compound	LOD (µg L^{-1}) [a]	r^2	LR (µg L^{-1}) [c]	RSD% [d] (*n* = 5)
DMP	0.22	0.995	1.0-500	4.8
DEP	0.33	0.992	1.0-500	5.6
BBP	0.25	0.996	1.0-400	6.1
DBP	0.27	0.994	1.0-500	5.2

[a] Limit of detection for S/N = 3., [b] Limit of quantification for S/N = 10., [c] Linear range.
[d] Relative standard deviation at concentration level of 50.0 µg L^{-1} for each PEs.

Analysis of environmental water samples

Located at the optimum conditions, the method performance was verified by analyzing the analytes in the four different environmental water samples. The results showed that the real samples were free of PEs contamination. IL-UA-ISFME is a non-exhaustive extraction procedure and the relative recovery (determined using the ratio of the concentrations found in the real environmental sample and reagent water sample, spiked with the same amount of analytes), was employed to assess the method accuracy in complex matrixes. The relative recovery experiments are summarize in Table 2 and were between 90-107%, demonstrating that the method is not remarkably affected by the matrixes in actual applications. Furthermore, reasonable RSD% values (below than 7.2%, *n* = 5) were achieved in the real sample analysis. The chromatograms obtained after performing IL-UA-ISFME-HPLC-UV Persian Gulf sample before and after spiking of the PEs are presented in Figure 6 and proved no considerable intervention pointing to the analytical procedure.

Table 2. The results acquired from analysis of real environmental water samples.

Sample	DMP	DEP	BBP	DBP
Caspian Sea (Amol, Iran), (5.0 µg L^{-1} added)				
PAHs concentration (µg L^{-1})	ND [a]	ND	ND	ND
Found after spike (µg L^{-1})	4.5	5.3	4.6	4.7
Relative recovery%	90	106	92	94
RSD% (*n* = 5)	6.2	5.8	7.1	6.4
Persian Gulf (Bushehr, Iran), (20.0 µg L^{-1} added)				
PAHs concentration (µg L^{-1})	ND	ND	ND	ND
Found after spike (µg L^{-1})	21.2	19.2	20.6	20.9
Relative recovery%	106	96	103	105
RSD% (*n* = 5)	7.2	5.4	5.9	6.9

Table 2. Continued

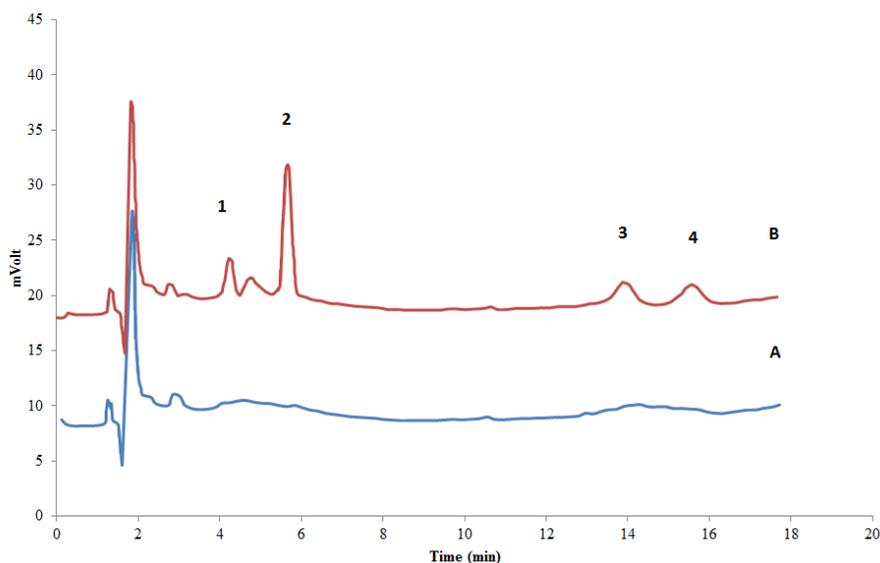| Jajroud River (Tehran, Iran), (50.0 µg L^{-1} added)				
PAHs concentration (µg L^{-1})	ND	ND	ND	ND
Found after spike (µg L^{-1})	53.2	48.5	52.7	53.4
Relative recovery%	106	97	105	107
RSD% ($n = 5$)	7.0	5.1	7.1	6.7
Latian Dam (Karaj, Iran), (100.0 µg L^{-1} added)				
PAHs concentration (µg L^{-1})	ND	ND	ND	ND
Found after spike (µg L^{-1})	106.2	92.3	94.9	103.7
Relative recovery%	106	92	95	104
RSD% ($n = 5$)	5.6	6.9	6.1	6.8

[a] Not detected.

Figure 6. The chromatogram of Persian Gulf sample (A): before and (B) after spiking PEs at the concentration level of 20.0 µg L^{-1} of each analyte; (1): DMP, (2): DEP, (3) BBP and (4) DBP.

CONCLUSIONS

This study provides the successful development and application of IL-UA-ISFME method followed by HPLC-UV for the trace determination of the selected PEs in environmental water samples. The satisfactory extraction efficiency, adequate sensitivity and repeatability in addition to significant accuracy and linearity over a broad range were achieved, approximately independent of the complicated matrixes in the real samples analysis. Moreover, by applying IL as extracting solvent, the proposed method is a green approach towards sample preparation in analytical chemistry. The whole analytical technique presents a cost-effective and quick way for the screening purposes. Hence, considering all the mentioned advantages simultaneously, the method owns outstanding potentials to be employed in the other environmental and biological screenings.

Disclosure statement

The authors declared no conflict of interest.

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