PREPARATION OF A POLAR MONOLITHIC COATING FOR STIR BAR SORPTIVE EXTRACTION OF EMERGING CONTAMINANTS FROM ENVIRONMENTAL WATERS

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Abstract

A new polar monolith based on poly(poly(ethylene glycol) methacrylate-*co*-pentaerythritol triacrylate) (poly(PEGMA-*co*-PETRA)) was first synthesised, after the optimisation of the polymerisation conditions, and applied as a coating for the stir bar sorptive extraction (SBSE) of a group of pharmaceuticals and personal care products (PPCPs) from environmental water samples.

Several parameters affecting extraction and liquid desorption in SBSE were investigated to achieve the optimal sorption efficiencies for the studied analytes. Under the optimised experimental conditions, a rapid, simple and sensitive SBSE performance was provided by the in-house monolithic stir bar. Moreover, the in-house coating was able to extract and desorb most of the studied analytes more effectively and quickly, due to its polar behaviour and suitable mechanical and physical properties, in comparison with the recently commercialised polar stir bars (EG Silicone Twister® and Acrylate Twister®).

The analytical methodology, including SBSE followed by liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS), was validated and successfully applied for the determination of a group of PPCPs in wastewater samples.

1. Introduction

Over the last few years, stir bar sorptive extraction (SBSE) has gained popularity as an extraction technique for the determination of emerging organic contaminants (EOCs) in complex matrices due to its environmentally friendly performance, simplicity and sensitivity [1-3].

Although SBSE has successfully been applied for the determination of organic contaminants in environmental, biological and food matrices at trace levels prior to a chromatographic technique [4-7], its main drawback is the availability of commercial coatings. Until very recently, polydimethylsiloxane (PDMS) was the only commercially available coating for SBSE, known by the name PDMS Twister® from Gerstel, being suitable for the extraction of those analytes with more apolar characteristics (i.e. log $K_{o/w}$ > 3) [3,8]. In order to overcome the limitations of PDMS for the extraction of more polar compounds, very recently, two new commercial coatings have been introduced by Gerstel, known as EG Silicone Twister® and Acrylate Twister®. Both are PDMS-based, the former modified with poly(ethylene) glycol (PEG), and the latter with polyacrylate (PA). Few studies have reported the use of these new coatings for SBSE to determine volatile organic compounds (VOCs) in cosmetic samples [9], benzothiazole [10] and pharmaceuticals and personal care products (PPCPs) [11] in wastewaters. All of these studies demonstrated a certain improvement on the extraction efficiencies of the most polar analytes in comparison with the classical PDMS coating. Nevertheless, new approaches in the development of SBSE coatings with polar functionalities are required to improve the extraction of more polar analytes and to extend the range of SBSE applications.

Up to now, many efforts have focused on the preparation of novel polar coatings for SBSE and several synthetic strategies have been developed. The first of these was sol-gel technology, which allowed novel materials to be obtained based on PDMS modified with β-cyclodextrin to determine estrogens and bisphenol A in water

samples [12] or based on PDMS modified with poly(vinylalcohol) to extract organophophorus pesticides in honey [13], among others. All of these coatings, chemically attached to a glass bar, were shown to be more thermally and chemically stable as well as more effective in terms of extraction efficiencies of both polar and apolar target analytes than with PDMS coating [1]. However, the sol-gel process involved more laborious steps during the polymerisation than other strategies, such as the preparation of monoliths.

Along the same lines, the second approach was the development of monolithic materials, which have became popular in recent years due to their high permeability and simplicity in preparation. For these reasons, a number of monolithic coatings with different chemical behaviours have been synthesised for SBSE applications. Some examples of this approach consisted of vinylphthalimide (VPA) and *N,N'*-methylenebisacrylamide (MBAA) to determine benzimidazoles in milk and honey [14] or, alternatively, vinylpyrrolidone (VPD) and divinylbenzene (DVB) to extract PPCPs from environmental waters [15], which enabled the effective extraction of polar compounds that were not retained onto the PDMS coating. In addition, this simple strategy has enabled a porous structure with high surface areas to be developed which results in an enhancement of extraction efficiencies [1,16].

Monolithic materials are highly versatile in comparison with the classic PDMS stir bar because different interactions can be achieved depending on the monomers used during their syntheses. To the best of our knowledge, there is no report that has previously used poly(ethylene glycol) methacrylate (PEGMA) as a functional monomer and pentaerythritol triacrylate (PETRA) as a cross-linker for the preparation of a monolith. The polar nature of both monomers might significantly increase the polarity of the final monolith. Therefore, the aim of this paper is the development of a polar monolithic coating for SBSE by the copolymerisation of PEGMA and PETRA monomers. Furthermore, its SBSE performance, followed by liquid chromatography-mass spectrometry in tandem (LC-MS/MS), was applied to extract PPCPs from wastewater samples.

2. Materials and methods

2.1. Chemicals and reagents

For the synthesis of the monolithic coating, PETRA (technical grade) and PEGMA (M_n~526) as monomers, and cyclohexanol (99%) and methanol (MeOH) (99.7%) as porogens were purchased from Sigma-Aldrich (Steinheim, Germany); 2-2'-azobis(isobutyronitrile) (AIBN) as initiator was supplied by BDH (Poole, UK). The monomers were purified by passing them through a short column filled with neutral alumina and the initiator was recrystallised at a low temperature from MeOH prior to use.

For the evaluation of the polar sorptive material, paracetamol, caffeine, antipyrine, benzotriazole, propranolol hydrochloride, pridinol methanesulfonate salt, methylparaben, carbamazepine, propylparaben, 2,4-dihydroxybenzophenone (DHB), benzylparaben, 2,2-dihydroxy-4-methoxybenzophenone (DHMB), diclofenac, benzophenone-3 (BP-3), triclocarban and triclosan were purchased from Sigma-Aldrich (Steinheim, Germany) (>97%). The structures, pK_a and log $K_{o/w}$ values of these analytes are presented in Fig. 1. Individual standard solutions of 1000 mg L^{-1} of each compound were prepared in MeOH and a standard mixture solution of 10 mg L^{-1} was prepared weekly in MeOH. The standard mixture solution was diluted daily with ultrapure water to give the required concentration and stored at 4ºC.

For LC analyses, HPLC grade MeOH and acetonitrile (ACN) were supplied by Prolabo (Llinars del Vallès, Spain); formic acid (HCOOH) (≥95%), sodium chloride (NaCl) (99%) and sodium hydroxide (NaOH) (≥98%) were purchased from Sigma-Aldrich (Steinheim, Germany). Ultrapure water was obtained from a water purification system (Veolia, Sant Cugat del Vallès, Spain).

2.2. Stir bar preparation

The detailed preparation of the poly(PEGMA-*co*-PETRA) monolithic coating is described in our previous study [17]. The ratios of the reagents and the polymerisation conditions were as follows: a ratio between monomers of 50/50 (% w/w), a ratio between total monomers and porogen of 40/60 (% w/w), a porogenic solvent consisted of 50% (w/w) cyclohexanol and 50% (w/w) MeOH, AIBN (1 mol% relative to polymerisable double bonds), polymerised in a water bath at 60ºC for 24 h. After the polymerisation, the monolithic stir bar was washed with MeOH, being stirred overnight. The final poly(PEGMA-co-PETRA) had the following dimensions: 12 mm in length and a polymer thickness of 1 mm, which corresponds to a polymer volume of 225 µL.

2.3. LC-(ESI)-MS/MS analysis

The extracts were analysed with an Agilent 1200 series LC coupled to a 6410 series triple quadrupole mass spectrometer with an electrospray ionisation (ESI) interface, an automatic injector (volume injected was 50 µL), a degasser, a quaternary pump and a column oven from Agilent Technologies (Waldbronn, Germany).

The chromatographic column was a Kromasil 100 C_{18} (150 x 4.6 mm i.d.) with 5 µm particle size from Teknokroma (Barcelona, Spain). ACN and ultrapure water adjusted to pH 3 with HCOOH were used as the mobile phase. The gradient started increasing from 15% to 55% ACN in 12 min (held for 5 min), then to 95% ACN in 8 min and kept constant for 3 min. Finally, it decreased back to the initial conditions in 2 min. The chromatographic analyses were performed at 45ºC with a flow rate of 0.6 mL min^{-1}.

A flow injection of a standard solution of each compound was used to find the optimal conditions in the ESI source. These conditions were as follows: nebuliser

pressure of 45 psi, drying gas (N_2), flow rate of 12 L min^{-1}, source temperature of 350ºC and a capillary potential of 4000 V. Ionisation mode, cone voltage and collision energies were optimised for each analyte in order to obtain two multiple reaction monitoring (MRM) transitions. The conditions are described in Table 1.

2.4. Stir bar sorptive extraction

The SBSE procedure was as follows: the stir bar was inserted into a 100-mL flask with 50 mL of sample adjusted to pH 7, containing 15% of NaCl. Samples were stirred at 500 rpm for 1 hour at room temperature (25ºC). After extraction, the stir bar was removed from the sample using magnetic tweezers and dried with a lint-free tissue. In terms of the liquid desorption (LD), the stir bar was immersed in a vial containing 5 mL of a mixture of MeOH/ACN (1/1, v/v), stirring at the same speed for 10 min. The extracts were then evaporated to dryness under a gentle stream of N_2. Prior to the LC injection, the extracts were redissolved in 1 mL of MeOH/H_2O (1/1, v/v). After each use, the stir bar was cleaned 3 times with 5 mL MeOH/ACN (1/1, v/v), stirring for 10 min. Each stir bar was reused at least 20-30 times with environmental samples.

All of the environmental water samples (from an influent, secondary effluent and tertiary effluent of a domestic sewage treatment plant (STP)) were collected in pre-cleaned amber glass bottles, filtered using a 0.45 µm nylon membrane (Supelco, Bellefonte, PA, USA), acidified to pH 3 (HCOOH) and stored at 4ºC until analysis.

3. Results and discussion

3.1. LC-(ESI)MS/MS conditions

MS/MS parameters were also optimised by injecting each compound at 250 µg L^{-1} in MeOH/H_2O (1/1, v/v) individually in flow injection analysis (FIA). Depending on their acidic or basic properties, the studied compounds were divided, individually or

in groups, into six windows applying negative or positive ESI ionisation. In addition, identification and confirmation MRM transitions were selected for each analyte. The optimised cone voltage and collision energy for each MRM transition are summarised in Table 1.

All of the selected compounds showed good linearity ($r^2 \geq 0.997$) by direct injection with a linear range of 0.50-200 μg L^{-1}, except for paracetamol, antipyrine, DHMB, triclosan (2-200 μg L^{-1}) and pridinol (25-200 μg L^{-1}). The limits of detection (LODs), calculated as signal-to-noise ratio (S/N) of 3, ranged from 0.15 to 0.50 μg L^{-1}, except for pridinol (5 μg L^{-1}).

3.2. Optimisation of the SBSE procedure

To overcome the lack of availability of polar commercial stir bars, over the last few years, several monomers with different polarities have been combined in order to synthesise polar monoliths [1,16]. There are several monomers whose polarity properties might be very beneficial. However, they have not been used in the preparation of a monolith yet. In our previous research [17], a monolith coating for SBSE based on poly(PEGMA-*co*-PETRA) was first synthesised. The choice of these monomers was dependent on the final chemical and physical properties of the desired monolithic material. Therefore, thanks to the hydroxyl and ester functional groups of both PEGMA and PETRA, the resulting monolith was expected to contribute to the sorption of more polar compounds onto the coating. In addition, the use of PEGMA resulted in a gelatinous polymer, providing mechanical stability and swelling capacity.

Subsequently, the evaluation of this polar monolithic material as SBSE coating was performed. Bearing in mind the polar structure of the resulting monolith, a group of PPCPs with different polarities was selected to test the extraction efficiency of our in-house coating and compare it with the commercial stir bars [11,15,18]. Then, in order to obtain high extraction efficiencies, several main parameters involved in the

extraction and desorption steps were optimised. In this study, desorption was performed by LD because the analytes were then separated by LC.

3.2.1. Extraction conditions

In terms of the optimisation of the extraction conditions, several factors, including sample pH, ionic strength, extraction time, agitation speed and temperature, have been taken into account for SBSE performance.

The SBSE procedure was optimised under these initial conditions: 50 mL ultrapure water spiked at 2 μg L^{-1} with the analytes' mixture stirring at 500 rpm for 1 hour at room temperature, and the LD was performed using 5 mL of MeOH stirring at the same speed for 10 min.

The effect of the sample pH on the analytes' response was evaluated at different pH values (3, 5, 7 and 9) because it may influence the analytes' sorption onto the coating. As expected, all of the analytes behaved according to their pK_a values (Fig. 1). For instance, diclofenac (pK_a = 4.2) showed a lower response when the pH was different from 3 because it was turned into its anionic form. In contrast, those compounds with pK_a around 9 presented higher signal response when higher pH values were applied (from 3 to 7) because they were uncharged, promoting the hydrophilic interactions with the coating, and their sorption onto it decreased to pH 9 because these analytes were almost in their anionic state. In addition, carbamazepine and caffeine showed an increase in their response when the sample pH was higher (from 3 to 9) due to their high pK_a values (> 13). The above trend can be seen in Fig. 2 where the effect of the sample pH for a representative group of analytes is shown. Since most of the target analytes showed better responses at pH 7, this pH value was selected as the optimal sample pH for further research.

The addition of salts, such as NaCl, has been demonstrated to modify the ionic strength of the sample solution and, as a consequence, increase the response of more polar analytes [1]. Therefore, the ionic strength of the sample was adjusted by the addition of NaCl from 0% to 30% w/v. In the range from 0 to 15%, it was observed that almost all the analytes presented higher sorption onto the coating at higher percentages of NaCl. However, with the highest percentage (i.e., 30%) of NaCl, their signal responses decreased. These results could be explained by the salting-out effect, which provided higher responses for the analytes, and then, when 30% of NaCl was added, the electrostatic interactions between the analytes and the salt ions caused a decrease in their signal responses [19]. Therefore, the addition of 15% of NaCl was chosen to provide better results for most of the studied analytes.

Regarding extraction time, the SBSE time was varied between 1 and 8 h. Fig. 3 details the effect of the extraction time on the analytes' response for a representative group of compounds. It was observed that the analytes almost reached the equilibrium in just 1 hour, except triclocarban, whose sorption onto the coating was lower than the rest of the compounds due to its apolar behaviour. When longer extraction times were applied, no significant improvement on the analytes' response was observed. As a compromise between the sensitivity and the time consumed, 1 h was selected as the optimal extraction time. This extraction step was performed in a short period of time in comparison with those provided by other in-house or commercial stir bars reported previously, which needed between 2 and 6 h to guarantee the achievement of the equilibrium at similar stirring rates or even higher [10,11,15,18,20,21]. As mentioned previously, the presence of PEGMA provides high permeability and swelling capacity to the monolith, which enables the analytes to go more easily into the in-house coating and interact quickly with the polar functionalities, providing a rapid SBSE performance.

The agitation speed was also studied and two agitation rates (500 and 1000 rpm) were tested. It was observed that similar results were obtained at both agitation speeds. However, it is expected that at a higher agitation speed, the monolithic

coating would be damaged. Thus, to keep the integrity of our in-house stir bar, the agitation speed was set at 500 rpm for further analyses.

Finally, the extraction temperature was maintained constant at 25ºC during SBSE experiments, since no marked improvement in the analytes' response was observed at higher temperatures.

3.2.2. Liquid desorption conditions

To ensure the complete desorption of the analytes, different solvents were tested under the optimised extraction conditions: MeOH, ACN and a mixture of MeOH/ACN (1/1, v/v). When 5 mL of these desorption solvents were evaluated, it was observed that ACN provided a higher signal response than MeOH for all of the compounds. Moreover, stirring with 5 mL of a mixture of MeOH/ACN (1/1, v/v), slightly higher analyte responses were obtained in comparison with ACN. Therefore, a mixture of MeOH/ACN (1/1, v/v) was chosen as the desorption solvent for the subsequent experiments. When the solvent volume was increased up to 10 mL, the LD results did not improve. Finally, 5 mL of a mixture of MeOH/ACN (1/1, v/v) was selected to provide the best results and 5 mL was the minimum volume necessary to cover the in-house stir bar sufficiently, immersed in the desorption solvent.

In order to ensure the complete desorption of the target analytes from the polar coating, the desorption time was also investigated between 5 and 30 min. It was observed that stirring for 10 min was long enough to desorb all of the analytes from the in-house stir bar and it was selected as the optimal desorption time.

After the optimisation procedure, the SBSE conditions used for a further application in environmental waters were as follows: 50 mL of sample at pH 7, containing 15% of NaCl, extracted at room temperature by stirring at 500 rpm for 1h for the extraction and 5 mL of a mixture of MeOH/ACN (1/1, v/v), stirring at the same

speed for 10 min for the LD. Under the optimal conditions, the recovery values (%) for each analyte in ultrapure water are detailed in Table 2. The in-house stir bar was able to extract most of the compounds with recovery values between 13% and 64%, except for paracetamol, caffeine, benzotriazole and antipyrine (2% to 9%).

3.4. Comparison to commercial stir bars

The SBSE performance of the poly(PEGMA-*co*-PETRA) monolithic coating was compared with two commercially available polar stir bars (EG Silicone Twister® and Acrylate Twister®), which have recently been commercialised by Gerstel. These commercial stir bars have been applied for the extraction of EOCs from environmental waters [11]. From that study, it was observed that, in fact, the polar commercial coatings were not as effective as expected under their optimised SBSE conditions. Table 2 shows the low recovery values obtained when both commercially available coatings were applied in SBSE of ultrapure water. While the Acrylate Twister® was not able to recover even the most apolar compounds, such as DHMB, BP-3 or triclocarban, the EG Silicone Twister® provided slightly better SBSE performance for those compounds with more apolar behaviour. However, both commercial coatings were barely capable of extracting the most polar analytes (%R < 3% for those with log $K_{o/w}$ < 3.4) even after a 4 hours extraction. In contrast, the SBSE using the in-house coating provided higher recovery values for more polar compounds, extracting for only 1 h, especially for those analytes with log $K_{o/w}$ between 1.9 and 3.4, achieving recovery values from 13% to 55%. This notable improvement could be explained by the fact that a high number of hydroxyl and ester functional groups are present in the monolithic structure.

Most of the in-house coatings synthesised in the past have shown progress in terms of extraction efficiencies and sensitivity. However, their use still involved long extraction times (< 2 h) [14,15,18,19]. In this paper, the use of the in-house monolith as the SBSE coating enabled better and less time-consuming extraction of the studied analytes than those using the commercial or in-house stir bars, due to

its suitable physical properties and high swelling capacity, promoting the diffusion of the analyte through the monolithic material. Moreover, the high permeability and hydrophilicity of PEG-acrylate or PEG-diacrylate monomers have recently reported when they were used to synthesise monolithic columns applied in normal phase and capillary LC for the separation of small molecules, such as peptides and proteins [22-25].

3.5. Application to environmental water samples

After SBSE optimisation, the in-house stir bar was applied for the extraction of PPCPs in environmental waters, such as influent and secondary effluent samples from a wastewater treatment plant (WWTP).

Taking into account the application of SBSE in complex matrices and the use of a ESI interface in LC-MS/MS, the effect of the ion suppression/enhancement was evaluated for influent and effluent wastewaters and calculated as the percentage decrease in the signal intensity obtained by the target analytes spiked at 100 µg/L after the extraction of 50 mL of real sample versus the intensity of the same amount of the analytes in ultrapure water [26]. As expected, higher values of ion suppression/enhancement were obtained in influent than in secondary effluent wastewaters due to the complexity of the matrix. For secondary effluent wastewater samples, this effect ranged from -6% to 27%, except for paracetamol and caffeine, whose ion suppression values were the highest ones, 31% and 43%, respectively. In contrast, the ion suppression/enhancement values for influent wastewaters increased and ranged between -22% and 24%, except for paracetamol, caffeine, methylparaben, propylparaben and triclocarban (29% to 48%). Moreover, similar results with respect to this effect were obtained when these analytes were extracted using commercial stir bars, providing ion suppression/enhancement values between -5% and 25%, except for propylparaben (44%) and triclocarban (54%) [11]. Although the resulting effect of ion suppression/enhancement was slightly significant for some compounds, especially the most polar ones, higher matrix

394 effects (from -40% to 65%) were found when using other extraction techniques,
395 such as solid-phase extraction (SPE), in comparison to SBSE, as reported
396 previously [27-29].
397
398 The recovery values of the analytes when the in-house stir bar was used to extract
399 PPCPs from wastewater samples are listed in Table 3. The recoveries obtained for
400 both secondary effluent and influent wastewaters were slightly lower than those
401 achieved in ultrapure water (15% to 54% for the most apolar compounds). It should
402 be pointed out that, taking into account the poor sorption of pridinol onto the
403 coating, it was expected that this compound would not be recovered from real
404 samples.
405
406 Once the applicability of the in-house stir bar was demonstrated in real samples and
407 in order to compensate the ion suppression/enhancement, the method was
408 validated using a matrix-matched calibration with 50 mL of secondary effluent
409 wastewater. First of all, a blank sample was analysed and a number of compounds,
410 such as propranolol, carbamazepine, benzylparaben, BP-3, triclocarban and
411 benzotriazole, were detected. The calibration was then achieved by subtracting the
412 signal of existing analytes in the blank. All of the compounds showed good linearity
413 in a range between 50 and 5000 ng L^{-1}, except for DHMB (100-5000 ng L^{-1}),
414 diclofenac (500-5000 ng L^{-1}) and triclocarban (100-5000 ng L^{-1}), with regression
415 coefficients (r^2) greater than 0.997 (except for propranolol ($r^2 > 0.991$)). The limits of
416 quantification (LOQs) obtained were between 50 and 500 ng L^{-1} and the LODs
417 ranged from 15 to 20 ng L^{-1} for all of the compounds, except for diclofenac (50 ng L^{-1}).
418 Particularly, in the case of benzotriazole, which registered a high signal in the
419 blank, the LOD was tentatively calculated as three times the standard deviation of
420 the analyte signal in the blank (n=3). The repeatability and reproducibility between
421 days of three samples spiked at 2000 ng L^{-1}, expressed as % relative standard
422 deviation (% RSD), were lower than 16% and 20%, respectively. In the present
423 work, apart from the development of a rapid SBSE, this analytical methodology
424 enabled a suitable method validation for all of the studied compounds, including

those with polar behaviour, which were hardly recovered at all using the commercially available stir bars and for which, consequently, the validation method could not be applied [11].

The SBSE/LC-MS/MS method was then applied to the analysis of different environmental samples, such as influent, secondary effluent and tertiary effluent wastewaters. It is important to mention that the tertiary effluent wastewaters were included in the following quantification because the effective treatment plant, based on reverse osmosis, should provide clean water samples in order to reuse them again. For this reason, it was also decided to check the occurrence of the studied analytes at this point. The concentrations found for each analyte in the different wastewater samples are shown in Table 4. As can be seen, all of the studied analytes were detected in the analysed samples, except antipyrine, DHMB and triclosan. In influent wastewaters, the highest levels of ng L^{-1} were recorded for paracetamol, caffeine, benzotriazole, propylparaben, diclofenac and BP-3 (626.9 – > 5000 ng L^{-1}). After the secondary treatment, it was observed that most of the studied compounds were effectively removed from the wastewaters, except benzotriazole, propranolol, carbamazepine, diclofenac, BP-3 and triclocarban. However, some analytes, such as benzotriazole, DHB and BP-3, still remained, even after the tertiary treatment (62.1, 155.9 and 160.7 ng L^{-1}, respectively), being discharged into groundwaters and surface waters to reuse them. The presence of this group of PPCPs in similar samples was reported previously [18,30,31] with results that are strongly in line with the present study.

4. Conclusions

After an optimisation procedure including both synthesis and extraction, this was the first time that a polar monolithic coating for SBSE based on poly(PEGMA-*co*-PETRA) has successfully been applied for the extraction of a group of PPCPs from wastewaters. The presence of PEGMA provides a high degree of permeability in the

polymer and promotes a high diffusion of the analytes, allowing rapid extraction in just 1 h.

Moreover, the results obtained in terms of extraction efficiencies for both polar and apolar compounds were better than those obtained using two new commercially available polar coatings (EG Silicone Twister® and Acrylate Twister®).

The combination of SBSE/LC-MS/MS was demonstrated for application in complex matrices, such as influent and effluent wastewaters, since no significant ion suppression/enhancement values were obtained for hardly any of the compounds (from -22% to 24%), except for paracetamol, caffeine, propylparaben and triclocarban.

Finally, the developed analytical methodology was evaluated in terms of linearity, LODs and precision, achieving low LODs (15-50 ng L^{-1}) for all of the selected compounds, overcoming the poor sorption of polar compounds onto the commercial stir bars. Moreover, the in-house coating for SBSE followed by LC-MS/MS allowed the detection and quantification of a broader range of analytes compared to commercial coatings in environmental water samples.

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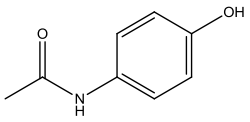
Figure captions

Fig. 1. Chemical structures, pK_a and log $K_{o/w}$ of target analytes.

Fig. 2. The effect of sample pH on the analyte response for a representative group of compounds, whose pK_a values are detailed in brackets.

Fig. 3. The effect of extraction time on the analyte response for a representative group of compounds.

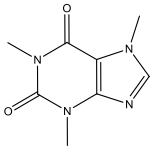
Figure



Paracetamol

pK_a 9.2

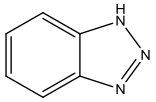
Log $K_{o/w}$ 0.5



Caffeine

pK_a 13.4

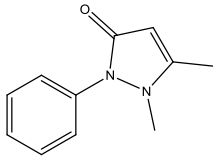
Log $K_{o/w}$ -0.6



Benzotriazole

pK_a 8.5

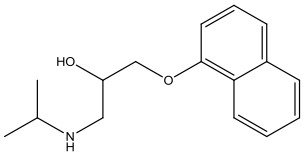
Log $K_{o/w}$ 0.4



Antipyrine

pK_a 13.3

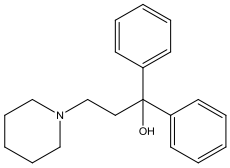
Log $K_{o/w}$ 1.4



Propranolol

pK_a 9.5

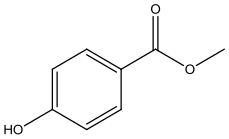
Log $K_{o/w}$ 2.9



Pridinol

pK_a 9.7

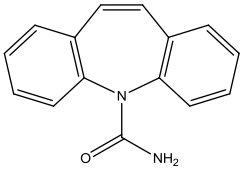
Log $K_{o/w}$ 3.4



Methylparaben

pK_a 8.3

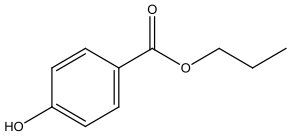
Log $K_{o/w}$ 1.9



Carbamazepine

pK_a 13.7

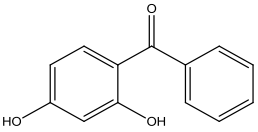
Log $K_{o/w}$ 1.9



Propylparaben

pK_a 8.2

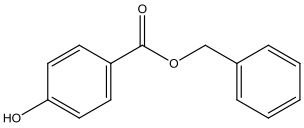
Log $K_{o/w}$ 2.9



DHB

pK_a 7.7

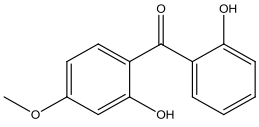
Log $K_{o/w}$ 3.2



Benzylparaben

pK_a 8.2

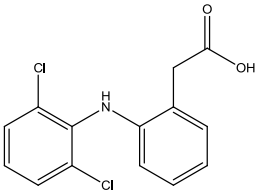
Log $K_{o/w}$ 3.6



DHMB

pK_a 7.1

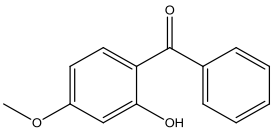
Log $K_{o/w}$ 4.3



Diclofenac

pK_a 4.2

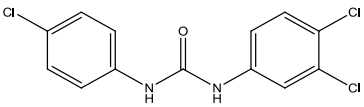
Log $K_{o/w}$ 4.5



BP-3

pK_a 7.6

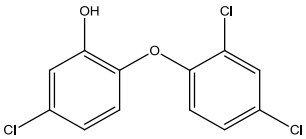
Log $K_{o/w}$ 4.0



Triclocarban

pK_a 12.7

Log $K_{o/w}$ 6.1



Triclosan

pK_a 7.9

Log $K_{o/w}$ 5.3

*pK_a and Log $K_{o/w}$ calculated using Advanced Chemistry Development (ACD/Labs) Software V11.02 (© 1994-2012 ACD/Labs)

Figure

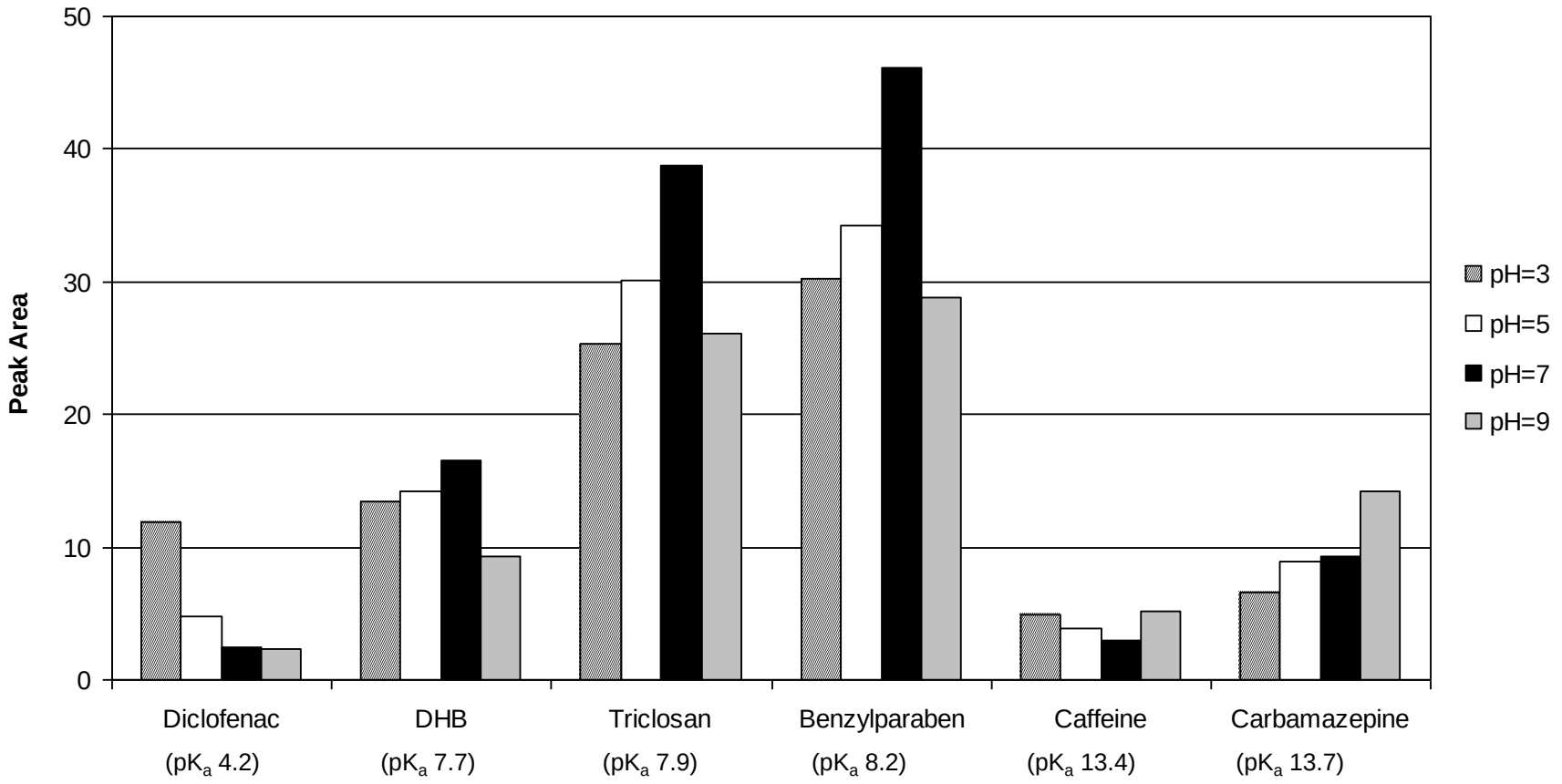


Figure 2

Figure

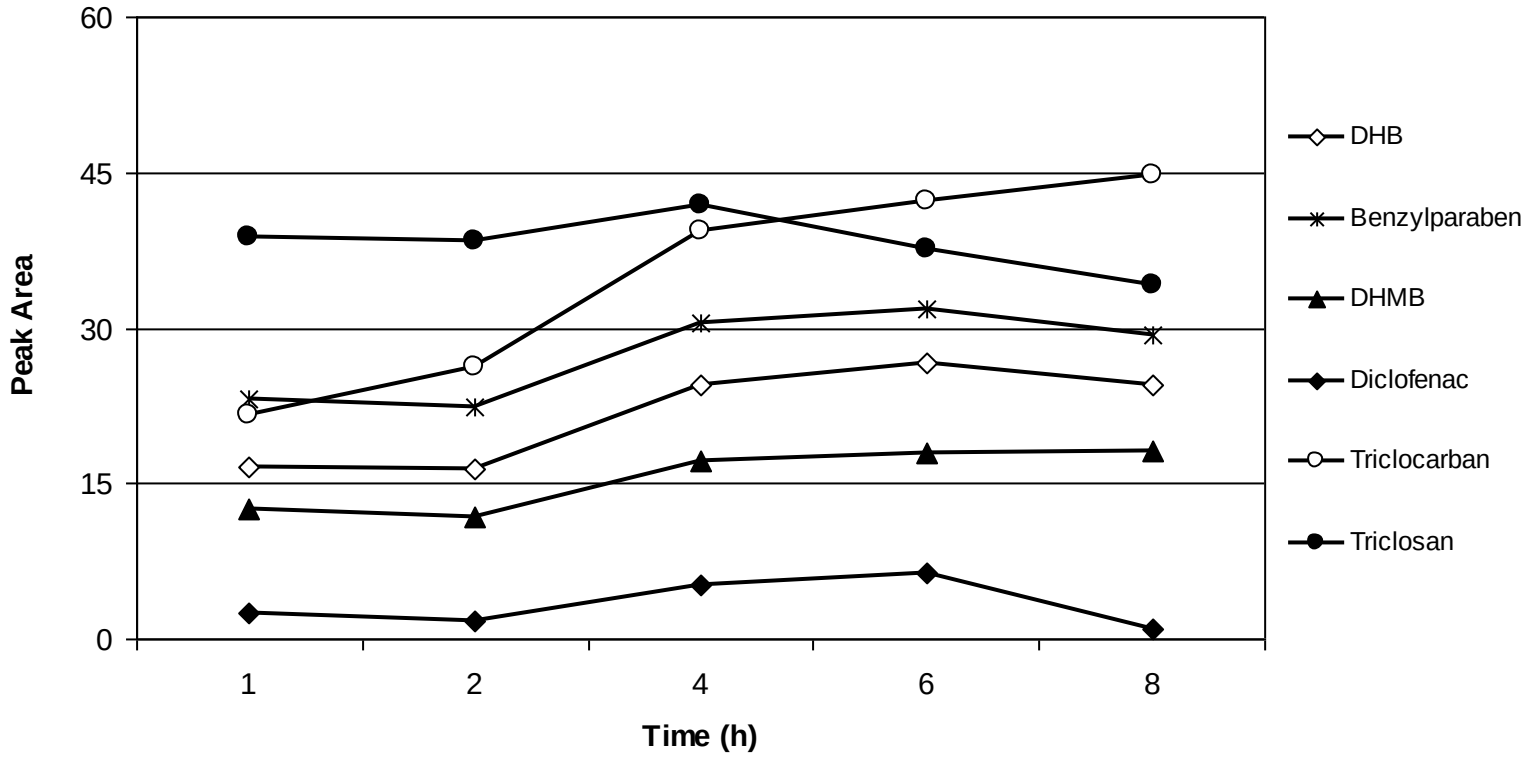


Figure 3

Table 1. LC-(ESI)MS/MS acquisition parameters in MRM mode for the analysis of the target analytes.

Analyte	Precursor ion (m/z)	Cone voltage (V)	Product ion (m/z) (Collision energy (V))		Ionisation mode (ESI)
			Identification	Confirmation	
Paracetamol	152	100	110 (15)	93 (25)	+
Caffeine	195	125	138 (15)	110 (25)	+
Benzotriazole	120	100	65 (25)	92 (15)	+
Antipyrine	189	100	145 (30)	115 (30)	+
Propranolol	260	125	116 (15)	183 (15)	+
Pridinol	296	125	115 (30)	193 (30)	+
Methylparaben	151	80	92 (15)	136 (5)	-
Carbamazepine	237	150	193 (35)	179 (35)	+
Propylparaben	179	100	92 (15)	136 (5)	-
DHB	213	130	135 (15)	169 (5)	-
Benzylparaben	227	100	92 (10)	136 (20)	-
DHMB	243	80	93 (15)	123 (15)	-
Diclofenac	294	75	250 (5)	214 (15)	-
BP-3	229	130	151(15)	105 (15)	+
Triclocarban	313	130	160 (5)	126 (15)	-
Triclosan	287 / 289	8	35 (18)	35 (18)	-

Table 2. Recovery values (%) obtained when different coatings were applied in SBSE of ultrapure water.

Analyte	Recovery values (%)		
	Poly(PEGMA-*co*-PETRA) [a]	EG Silicone Twister® [b]	Acrylate Twister® [b]
Paracetamol	5	-	<1
Caffeine	2	-	-
Benzotriazole	9	<1	<1
Antipyrine	2	<1	1
Propranolol	19	2	2
Pridinol	13	3	2
Methylparaben	20	1	2
Carbamazepine	25	<1	<1
Propylparaben	38	10	2
DHB	55	24	9
Benzylparaben	64	39	14
DHMB	56	26	9
Diclofenac	33	<1	<1
BP-3	55	45	10
Triclocarban	51	59	43
Triclosan	55	80	42

[a] 50 mL of sample spiked at 2 µg L^{-1}

[b] 50 mL of sample spiked at 4 µg L^{-1} [11]

Table 3. Recovery values (%) obtained for the studied analytes when the poly(PEGMA-co-PETRA) coating was applied in SBSE followed by LC-MS/MS of 50 mL of water samples spiked at 2 µg L^{-1} with the analyte mixture.

Analyte	Recovery values (%)	
	Secondary effluent WWTP[a)]	Inffluent WWTP[b)]
Paracetamol	3	4
Caffeine	1	2
Benzotriazole	8	9
Antipyrine	2	2
Propranolol	15	17
Pridinol	-	-
Methylparaben	12	14
Carbamazepine	19	24
Propylparaben	24	27
DHB	28	37
Benzylparaben	45	50
DHMB	36	42
Diclofenac	25	31
BP-3	44	54
Triclocarban	49	31
Triclosan	43	43

[a)] % RSD (*n*=3) < 15% for %R > 12%
[b)] % RSD (*n*=3) < 18% for %R > 14%

Table 4. Concentrations of found analytes in influent, secondary effluent and tertiary effluent wastewater samples when they were analysed using the in-house stir bar for SBSE followed by LC-MS/MS.

Analyte	Concentration (ng L^{-1})		
	Inffluent WWTP	Secondary effluent WWTP	Tertiary effluent WWTP
Paracetamol	> 5000	n.d.	n.d.
Caffeine	> 5000	<LOD	n.d.
Benzotriazole	3005.4	609.9	155.9
Antipyrine	n.d.	n.d.	n.d.
Propranolol	<LOQ	83.5	<LOQ
Pridinol	n.d.	n.d.	n.d.
Methylparaben	> 5000	n.d.	n.d.
Carbamazepine	n.d.	245.9	n.d.
Propylparaben	2369.4	n.d.	n.d.
DHB	372.1	<LOQ	62.1
Benzylparaben	<LOD	<LOQ	<LOQ
DHMB	n.d.	n.d.	n.d.
Diclofenac	966.0	641.0	<LOD
BP-3	626.9	217.6	160.7
Triclocarban	n.d.	125.0	<LOQ
Triclosan	n.d.	n.d.	n.d.

n.d. = non detected
% RSD (*n*=3) < 23%