Removing Residues of Pharmaceuticals in Aqueous Medium by Adsorption on Solid Phase

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The paper concern is development of a sensitive and selective method for determination of polar pharmaceutics from water samples. The method is used for the study of removing process of pharmaceutics from aqueous medium on solid phase. The concentration of some polar pharmaceutics is determined in influent and effluent of the municipal wastewater treatment plants (WWTP) from Cluj Napoca.

Keyword: Water samples, GC/MS, adsorption, pharmaceuticals, pollutants removal

Water pollution is a serious concern for scientists because of acute toxicities and carcinogenic nature of the pollutants [1-4]. The main sources of water contamination are industrial, domestic and agricultural activities as well as environmental and global changes [1, 2]. Among various water treatment methods, adsorption on solids is supposed as the best one due to its inexpensiveness, universal nature and ease of operation [1, 5-9].

The occurrence of pharmaceutical in the aquatic environment has been recognized as one of emerging issues in environmental chemistry. After intake, pharmaceuticals are excreted with urine and feces either as active substances or metabolites. The widespread presence of pharmaceuticals in the aquatic environment is due to their incomplete removal in wastewater treatment plants.

Pharmaceuticals are designed to target specific metabolic pathways in humans and animals but there is also concern that they may pose a potential risk to aquatic organisms at the low ng/L level [4, 10]. It is also assumed that pharmaceuticals could act as pseudo-persistent compounds, because of their continual discharge into aquatic media via WWTP effluents [6].

The contaminants, with special attention the compounds with biological activity, are necessary to be removed from environmental waters [11-13]. Due to dilution and degradation, lower concentration levels are expected for drugs after they enter the aquatic environment. To obtain detection limits in the order of ng/ L range the enrichment methods and very sensitive detection methods are necessary [4, 13].

The GC/MS is more common method used for isomer separation [14-16] and is a standard method applicable to determination of many classes of pollutants, according to European Water Framework Directive [17]. In the last decade were published an important number of paper on fate of pharmaceutical compound in the water environment [2-6, 10-13, 18-20] but very low data are available on trace of pharmaceutical as contaminates in Romania [21, 22].

The objective of the present paper is development of methods enable to be used in study of removal of pharmaceuticals from water samples based on adsorption processes involving active carbon and molecular sieves. Some results resulting from efficiency study on removal of few acidic pharmaceutics on solid materials are presented. Also are presented results on determination of removal rate of wastewater treatment plant (WWTP) on pharmaceutical compounds.

Experimental part

Sampling and sample preparation

The samples used for adsorption study of pharmaceutics on different solid phases were prepared in laboratory. The experiments were performed as following. For every studied adsorbent were prepared an initial solution (sample) in a Berzelius vessel of volume of 250 mL in which was added 100 mL distilled water and 1 mg of every pharmaceutical and 10 mg of solid phase. Also was prepared the blank sample (control sample) containing the pharmaceutical mixture in the same quantities but not adsorbent. The both, sample and control sample were stirred (300 rpm) at room temperature for four days. At every 24 h were collected 5 mL of sample and the pharmaceuticals were extracted by Liquid-Liquid (L-L) procedures [23, 24] using 2 mL of n-Hexane. The final extract was brought to 0.25 mL and after derivatization (sylilation) 2 μL was introduced in GC/MS system.

For investigation of the WWTP removal efficiency the samples were taken from Cluj Napoca WWTP in selected points. The samples were concentrated also by Liquid-Liquid (L-L) procedures using n-Hexane as organic phase. Were used a volume of 250 mL aqueous samples (with 250 ng of PCB added as internal standard) and 5 mL n-Hexane. After 30 min of mixing process at room temperature (22 °C) the organic phase was colected and concentrated to 250 μL. The sample was silylated and 2 μL was injected in GC/MS system.

To obtain the needed accuracy by gas chromatographic and mass spectrometry analysis the compounds were derivatized by silylation [22]. The derivatized compounds are thermally stable and interactions with metal surfaces are much lowered. By silylation procedure the active hydrogen is substituted by trimethylsilyl group $-Si(CH_3)_3$, (TMS). As reagent (N,O-bis (trimethylsilyl)-trifluoro-acetamide (BSTFA) of the formula $CF_3C=NSi(CH_3)_3$ $OSi(CH_3)_3$ was used. The reaction conditions were as follows: a) the sample is taken to dryness; b) the silylating reagent is added; c) the sample with the reagent maintained at 70 °C for 60 min; d) the sample is extracted in *iso*-octane and 2 μL injected into the GC/MS system.

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GC/MS analysis

The analyses were done on a GC/MS system (Thermo Electron Polaris Q). The mass spectrometer was operating in Electron Impact (EI) mode at 70 eV. The source temperature was 250 ^{0}C and emission current 300 μA. The gas chromatograph was equipped with a capillary column HP-5MS (30mm×0.25mm) with 0.25μm film thickness. The temperature was programmed from 90 ^{0}C (1 min) to 120 at10 ^{0}C /min and than to 200 at 3.5 ^{0}C/min and than to 315 at 5 ^{0}C/min (keeping this temperature for 11 min). The injector temperature was of 250 ^{0}C and 2 μL of sample was injected by splitless technique, with split flow 50 mL/min and splitless time 1 min. Mass spectra were obtained in full scan mode in the range of 50-650 Daltons.

Results and discussions

Adsorption of compounds on solid phase

Pharmaceuticals studied in this work were Ibuprofen, Indomethacin, Naptoxen and Carbamazepine. The basic structure of studied compounds is shown in table 1 and their mass spectra (silylated compounds) are shown in table 2. For removal of selected compounds from water were studied adsorption processes on some solid materials including two types of activated charcoal and four types of molecular sieves. The main characteristic of the used solid phase are Shown in table 3.

The activated carbon was reported as adsorbent of pollutant removal in numerously studies on aromatic compounds [26-31] or pharmaceutics [2-4, 5]. Few authors reported special form of carbon used in removal experiments [2, 10, 32-34]. The removal rate reported is in main depending on physical propriety of the material (granulation, specific surfaces) and hydrophobic character of the compounds.

In our studies the activated charcoal were selected having a grain size in the range 60-80 mesh (Charcoal - Service T.L. s.r.l., Milano, Italy) and a charcoal with a grain of 10 -18 mesh (Romcarbon, Buzău, România). Also the removal experiments reported were performed on molecular sieves (zeolites) [35-42]. Due of extensive us of zeolites for contaminates elimination from water were reported procedures for their synthesis [43, 44]. The results are a function of physical structure of the materials as well as of the ratio SiO_2/Al_2O_3. In our studies were used four types of molecular sieves of grain 60-80 mesh (Machery Nagel, Duren, Germany, 10-18 mesh (Carlo Elba Strumentazione Toscana, Italy), 18-70 mesh (Service T.L. s.r.l., Milano, Italy) and of 120-140 mesh (Service T.L. s.r.l., Milano, Italy).

The GC/MS separation of the target pharmaceutical, in conditions described in Experimental is shown in figure 1.

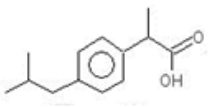
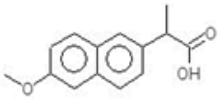
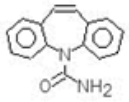
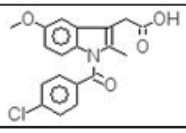
Nr	Name	Structure	Formula	M	CAS
1	Ibuprofen		$C_{13}H_{18}H_2$	206	15687-27-1
2	Naproxen		$C_{14}H_{14}O_3$	230	22204-53-1
3	Carbamazepine		$C_{15}H_{12}N_2O$	236	298-46-4
4	Indometacin		$C_{19}H_{16}ClNO_4$	357	53-86-1

Table 1
NAME, STRUCTURE, FORMULA, MOLECULAR WEIGHT (M) AND CAS NUMBER OF STUDIED COMPOUNDS

Ibuprofen		Naproxen		Carbamazepine		Indometacin	
m/z	I (%)	m/z	I (%)	m/z	I (%)	m/z	I (%)
160	100	185	100	193	100	139	100
73	89	243	74	192	21	312	37
117	37	141	45	194	18	141	32
161	33	302(M)	41	165	15	111	22
91	22	73	33	191	14	429(M)	21
115	20	170	32	166	6	73	16
263	18	115	26	73	5	158	14
234	15	153	22	164	5	314	13
145	16	287	17	139	3	431	9
205	8	254	15	100	3	173	7
278(M)	2	227	9	293	3	370	7
				308(M)	0		

Table 2
MASS SPECTRA OF STUDIED SILYLATED COMPOUNDS (1TMS)

Table 3

THE CHARACTERISTIC OF ADSORBENT MATERIALS; NAME, SYMBOL, PORE SIZE, GRAIN, SPECIFIC SURFACE, MOLAR RATIO SiO_2/Al_2O_3 AND INITIAL QUANTITY (ADDED TO 100 mL WATER) USED AT EXPERIMENT

Nr	Name	Symbol	Pore size (Å)	Grain (mesh)	Surface (m^2/g)	Molar ratio SiO_2/Al_2O_3	Initial quantity (mg)
1	*Charcoal SK-4*	C-1	100	60-80	396	-	10
2	*Hardwood Charcoal*	C-2	100	18-10	581	-	10
3	*Molecular sieve*	S-4	5	60-80	437	0.9105	10
4	*Molecular sieve*	S-6	5	18-10	407	1.2578	10
5	*Molecular sieve*	S-9	5	70-18	413	1.1924	10
6	*Molecular sieve*	S-10	5	120-140	406	1.2823	10

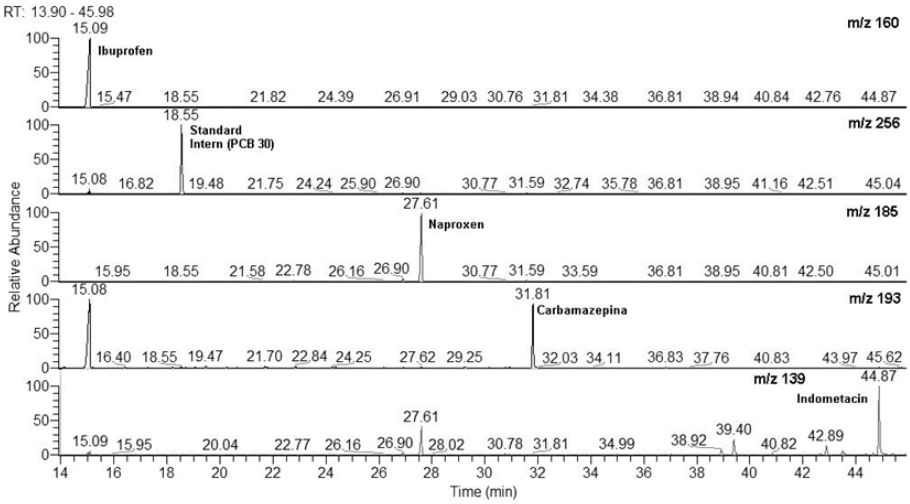


Fig. 1. GC- MS separation of compounds ibuprofen, naproxen, indomethacin and carbamazepin as silylated compounds (1 TMS)

For quantification of every compound the area of base peak were used. The results as percent from initial concentration, on six types of adsorbents (two activated carbon species and four species of molecular sieve) obtained in the range of four days are shown in the table 4.

Pharmaceuticals removal rate in WWTP

Before of elimination in environment, usually in receptors river, the used water must to be purified. The purification process is done in Wastewater Treatment Plant (WWTP) which has some main unit dedicates to mechanical, sedimentation or biological processes. The rate of removal

Compound	Day	Adsorbent					
		SK-4	*C-2*	*M-S4*	*M-S6*	*M-S9*	*M-S10*
Ibuprofen	0	100	100	100	100	100	100
	1	8.53	n.d.	35.17	27.29	83.80	28.61
	2	≤LOQ	10.76	33.75	11.89	60.37	11.48
	3	≤LOQ	20.36	n.d.	9.09	34.71	n.d.
	4	≤LOQ	32.46	8.8	5.17	66.78	7.8
Naproxen	0	100	100	100	100	100	100
	1	6.59	n.d.	n.d.	16.64	9.38	n.d.
	2	≤LOQ	n.d.	17.83	7.15	9.47	68.42
	3	≤LOQ	n.d.	n.d.	7.76	2.99	n.d.
	4	≤LOQ	35.28	13.20	n.d.	5.51	7.65
Carbamazepine	0	100	100	100	100	100	100
	1	50.83	n.d.	n.d.	27.33	27.5	53.10
	2	44.05	n.d.	55.81	n.d.	n.d.	n.d.
	3	43.93	n.d.	n.d.	16.37	n.d.	n.d.
	4	41.48	58.33	n.d.	16.74	n.d.	n.d.
Indometacin	0	100	100	100	100	100	100
	1	80.03	n.d.	57.88	74.32	62.48	14.46
	2	n.d.	n.d.	52.17	59.94	n.d.	10.36
	3	73.03	n.d.	35.40	45.14	60.63	5.03
	4	76.87	74.29	14.86	75.83	47.03	6.75

Table 4

CONCENTRATION OF STUDIED COMPOUND (% FROM DAY 0) AFTER FOUR DAY INTERACTING WITH ADSORBENT MATERIALS; (n.d NON DETERMINED, LOQ LIMIT OF DETECTION)

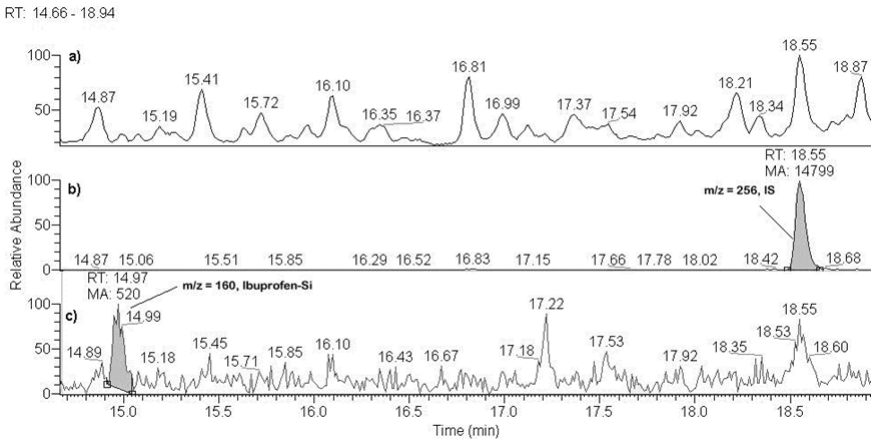


Fig. 2. GC/MS chromatogram on a sample collected from WWTP efluent; a) TIC chromatogram, b) Chromatogram on m/z 256 (Internal Standard), c) Chromatogram on m/z 160 (Ibuprofen)

Table 5

THE DATA RESULTS FROM WATER SAMPLES FOR SITES BEFORE AND AFTER BIOLOGICAL STAGE OF WWTP CLUJ-NAPOCA.

Compound	Elution time (min)	Molecular weight (M) (*)	Ion used for quantification (m/z)	Influent concentration [ng/L]	Efluent concentration [ng/L]	Removal rate [%]
Ibuprofen	15.09	278	160	245,92±13.2	11,88±1.05	95,17
SI	18.55	256	256	1000.00	1000.00	-
Naproxen	27.61	302	185	<LOQ (**)	<LOQ	n.d.
Carbamazepin	31.81	308	193	<LOQ	<LOQ	n.d.
Indometacin	44.87	429	139	<LOQ	<LOQ	n.d.

Note: *(*) is for molecular weight after sililation; (**) The detection limit obtained was of 10 ng/l.*

of pollutants is a fundamental objective for characterization of efficiencies of sewage treatment [22]. The pharmaceuticals are active biologic compounds and are recognized as Endocrine Disruptors (ED) being classified as priority pollutants by potential effects on human and animal organism. The one of objective of the present paper is to determination the removal rate of some common prescript pharmaceuticals as Ibuprofen, Naproxen, Carbamazepine and Indometacin in biological stage of WWTP from Cluj Napoca. The samples were collected from influent and effluent of WWTP from Cluj-Napoca. The compound concentration was performed by L-L process (using as extracting solvent n-Hexane) described in Experimental. The samples were collected in two different precipitation seasons: a dry one and a wed one respectively.

The good result was obtained in the dry period. In wed period in the effluent samples the concentration of compounds was under Limit of Detection (LOD). After concentration the samples were silylated and analyzed by GC/MS system. The quantification was performed using area of compounds from chromatogram on base peak and by comparisons with the peak area of the internal standard (PCB 30). The GC/MS chromatogram for a sample collected from WWTP effluent is shown in figure 2. The obtained data are shown in table 5 as an average on three samples. The removal rate obtained for ibuprofen by biological unit of 95.15 % is in accord with recent published papers on a pilot plant treating hospital wastewater [43, 45] or biological treatment efficiency using lab-scale suspended activated sludge [46].

For hydrofobic organic compounds of type galaxolide and tonalide, the biologic digestion is less efficient. For galaxolide removal rate was of 9.01 % and for tonalide the elimination was of 30.54 %. For these compounds like as for other hydrophobic compounds the main removal rate is by sedimentation proceses in the sedimentation unit of the WWTP.

Conclusions

The process of adsorption for Ibuprofen, Naproxen, Indomethacin and Carbamazepine were been studied in six kinds of adsorbents, two types of activated carbon and 4 kinds of zeolites (molecular sieves), for a period of interaction of 4 days (96 h).

Based on obtained data results as most effective general adsorbent the M-S10 molecular sieve in which case the three compounds Ibuprofen, Naproxen and Indomethacin are adsorbed within 4 days more than 93% and Carbamazepine are adsorbed in a proportion of about 47 %.

The specific adsorbents for selected compounds are: a) molecular sieve M-S10 for Ibuprofen and Indomethacin, with removal rate of 92.2 % and 93.3 % respectively; b) active carbon SK-4 for Naproxen, with removal rate of 93.4 %; c) molecular sieve M-S6 for Carbamazepine with removal rate of 83.24 %. This data are in accord with results reported by recent published paper [39] which concluding the retention rate is increasing for high values of the ratio Si/Al from zeolite.

The concentration determined for Ibuprofen in influent of WWTP from Cluj-Napoca was of 245.92 ng/L and of 11.88 ng/L in effluent. Removal rate for Ibuprofen by WWTP from Cluj-Napoca was 95.17 %. Therefore the compound concentration in efflent was of 4.83 % relative to influent. By dilution in the receptor river (River Somesul Mic with a flow of 12 m^3/s) the ibuprofen concentration is reduced to 1.98 ng/L. For the compounds Naproxen, Carbamazepina and Indomethacin the removal rate was not calculated because the concentrations were under limit of quantification (LOQ = 10 ng/L).

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