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## Effects of high-frequency electromagnetic treatment on the solid-phase extraction of aqueous benzene, naphthalene and phenol

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### Abstract

The influence of a high-frequency electromagnetic field on the ability of octadecyl bonded silica, poly-(2,6-diphenyl-*p*-phenyleneoxide)–Tenax GC and hydrophilized silica to preconcentrate benzene, naphthalene and phenol was tested. Breakthrough curves for aqueous solution of these compounds at pH 6.0 were evaluated with and without electromagnetic exposure of cartridges by spectrophotometric analysis of the fractions of the effluents. Elution curves of the analytes in methanolic eluates were measured in order to test the influence of the electromagnetic field on adsorption and desorption processes. The electromagnetic field was found to promote sorption of benzene and naphthalene from water onto Tenax GC increasing breakthrough volumes by a factor of 1.5–4.

*Keywords:* Solid-phase extraction; Microwave electromagnetic treatment; Benzene; Naphthalene; Phenol

### 1. Introduction

Sample preparation is often the most laborious and time-consuming stage in the analysis of water samples for organic and metal ion pollutants. Various techniques have been developed for the isolation and enrichment of these compounds [1]. Solid-phase extraction (SPE) is now widely used, becoming a standard method [2]. The solid supports mostly used in the SPE are bonded silicas and polymeric sorbents of various types [3,4]. The field of their application includes the isolation and concentration of aromatic hydrocarbons [5], azaarenes [6], chlorophenols [7], priority pollutants of different classes [8], heavy metal ions [4]. Different principles of chemical interactions of analyte molecules with sorbents are used for partition of the substances between the solid

support and the water. They include physical sorption, ion exchange, and complex formation [3,9].

Treatment with a microwave electromagnetic field is a relatively new highly efficient technique for promoting chemical reactions of different classes. Firstly developed for acid digestion of hardly decomposable samples [10], this method was successfully used for accelerating the reactions of imidization [11], epoxy resin curing [12], synthesis of various esters [13,14], nucleophilic fluoralkylation of secondary amines [15], synthesis of coordination compounds of different transition metals [16] and several other types of reactions [17,18].

Kubrakova et al. have shown [19] that a microwave electromagnetic treatment promotes sorption of some platinum group metals on the POLYORGS IV sorbent, which is a porous copolymer of styrene and divinylbenzene chemically modified by 3-(5-methylpyrazole) [20]. These authors have successfully

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demonstrated that the rate of the reaction of complex formation on the surface of the sorbent is at least twice larger and the degree of extraction is 10–15% higher in the presence of a microwave electromagnetic field, compared to experiments with conventional boiling at atmospheric pressure. On the other hand the system, investigated by Kubrakova et al. [19], is very complicated and the microwave irradiation can influence not only the processes on the surface of the sorbent but also chemical equilibria in the volume of solution, and it is difficult to distinguish the actual action of the field. In order to investigate the influence of the electromagnetic field treatment on adsorption processes simpler model systems are desirable.

The accumulation of the analyte compounds in the SPE column is most influenced by retention, which is the capacity factor of the analyte in the water–sorbent system. It was shown [21] that high breakthrough volumes can be obtained for columns even with a small number of theoretical plates, if the retention is high. One of the possible approaches for verification of the SPE methods is to measure the breakthrough curve for the analyte–water–sorbent system and the elution curves of the analyte for the organic eluent–sorbent–analyte system. Beside of the physico–chemical properties of the aqueous solution of the analyte and the given bed of the sorbent, retention is strongly influenced by the flow-rate of the solution through the bed. The higher the flow-rate and the further the distribution process from the state of equilibrium, the poorer is retention. Taking this into account, the factors which can intensify the mass transport processes in the column are important to increase accessible flow-rates and reduce the time of analysis.

Two popular types of solid supports, octadecyl bonded silica and poly-(2,6-diphenyl-*p*-phenyleneoxide) (Tenax GC), were chosen for comparison of their capacities for selected aromatic organic substances. Their surface is mainly unspecific, and it is possible to assume that interactions of sorbent–sorbate are relatively weak [24]. It is known that the state of equilibrium of the adsorption–desorption process for aromatic organic substances dissolved in water is reached quickly for bonded silicas [22] but it is sufficiently slow for Tenax GC [23]. The objective of this work was to evaluate the influence of

irradiation of the cartridges with these sorbents by a radio high-frequency electromagnetic field on the retention of benzene, naphthalene and phenol. The third sorbent–hydrophilized silica was tested with respect to its capability to form covalent bonds and retain phenol irreversibly forced by the field.

## 2. Experimental

### 2.1. Materials

Model aqueous solutions of benzene, naphthalene and phenol (chemically pure grade, Reachem, Russia) were prepared from stock solutions in methanol (chemically pure grade, Reachem). These stock solutions were diluted with methanol to serve also as the standard solutions for all recovery tests. MilliQ deionized water (Millipore, Bedford, MA, USA) was used. Sodium chloride (chemically pure, Reachem) was used as an electrolyte for salting out. The following sorbents were used as the solid supports: octadecyl bonded silica Separon SGX RPS (TESSEK, Prague, Czech Republic), carbon contents more than 22% [25], particle size 40–100  $\mu\text{m}$ ; poly-(2,6-diphenyl-*p*-phenyleneoxide) (Tenax GC, Alltech, Los Altos, CA, USA), pore diameter 140 nm, particle size 150–250  $\mu\text{m}$ ; non-modified silica (DIAX, Moscow, Russia), irregular, pore diameter 13 nm, average particle size 150–250  $\mu\text{m}$  [26]. The last sorbent was hydrophilized according to [24] by 12-h boiling in pure water. Acetone and carbon tetrachloride were of ‘chemically pure’ grade from Reachem.

### 2.2. Cartridge preparation

Pieces of 5 cm of polypropylene tube (2 mm I.D. and 2.5 mm O.D.) were used to prepare cartridge shells. This cartridge size was chosen in order to reduce the electromagnetic field nonuniformity across the cartridge axis on the one hand, and to keep the cartridge volume sufficient to make measurements on the other hand. At the end of the tubes 0.5 cm was flattened and a piece of silanized glass wool was placed at this end to support the sorbent. The empty cartridges were weighed. The suspension of sorbent powder in the mixture of acetone with

carbon tetrachloride, with the density approximately equal to that of the sorbent, was prepared to form a relatively stable composition. This sorbent suspension was then placed into the empty cartridge with a syringe and pumped through it to form a 1.5–2.0 cm long bed (bed volume was approximately 0.05 ml). The cartridges were closed with weighed pieces of glass wool, rinsed with two portions of 2–3 ml of acetone and flowed with dry air till constant weight. The weight difference between the cartridge prepared in this way and the empty cartridge with glass wool gave the amount of the sorbent.

### 2.3. Apparatus

A NP-1M peristaltic pump (Chimavtomatika, Moscow, Russia) was used to pump the solutions through the cartridges. The analyte concentration in each water fraction was measured using a Specord UV-Vis spectrophotometer (Karl Zeiss, Jena, Germany). Elution curve measurements were carried out with the help of the glass syringe pump of the liquid chromatograph 'Milichrom-1A' (OPO Nauchpribor, Orel, Russia) as a solvent reservoir. A modified high-frequency electromagnetic field generator PPBL-3 (Mozaika, Moscow) yielded the electromagnetic field ( $110 \pm 10$  MHz frequency, 0–250 mA anode current). The electric resonator of the electromagnetic field generator consisted of two coaxial coils, one and a half turns each. The generated field was not uniform, its intensity being larger near the coils and smaller at the axis of the solenoid. Maximal field intensity in the centre of the coil was calculated to be 10 A/m (0.12 Oersted). The diameter of the coils was 2.5 cm, total height of active zone 2.5 cm. Special precautions were undertaken to avoid leakage of the electromagnetic field to the outer space. The solenoid part of the device was surrounded by a metallic shield and the whole apparatus was thoroughly grounded. The scheme of the experimental set-up is shown in Fig. 1.

### 2.4. Measurements of absorbed energy of an electromagnetic field

For studying the influence of an electromagnetic field on chemical interactions of different types microwave ovens operating at 2450 MHz were

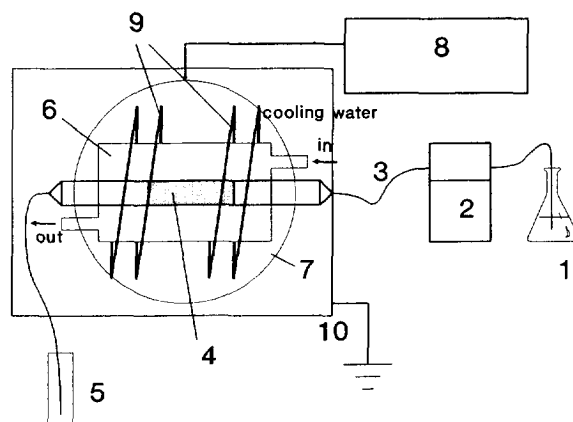


Fig. 1. Scheme of experimental set-up for high-frequency electromagnetic treatment of SPE cartridges: 1=reservoir with model solution; 2=peristaltic pump; 3=connection tubings; 4=sorbent bed; 5=receiving vessel; 6=cooling jacket; 7=electromagnetic field generator; 8=electromagnetic field generator power supply; 9=resonator coils; 10=grounded shield.

successfully used [10–13]. However, low reproducibility of heating was observed [10] when sample loads were less than 50 g. Kingston and Jassie [10] connected this fact with some temporal and geometrical inhomogeneity of the field produced in 2450-MHz devices and the difficulty of perfect adjustment of generation and absorption of electromagnetic energy. Lower frequencies (e.g. 110 MHz in this work) allow to use devices with simpler types of resonators, achieve a relatively uniform field in the resonator cavity and therefore obtain more reproducible results, when mild treating of small samples (less than 5 g) is needed.

The absorbed power of the electromagnetic field was detected by its thermo-action according to [10] by measuring the absolute changes in temperature of given volumes of water samples. The temperature measurements were made with a mercury thermometer with 0.2°C precision. As the mercury in the thermometer bulb absorbs electromagnetic power, all measurements were made immediately after the field was switched off. The volumes of the water samples were rather small (5 and 2.5 ml) and they lost heat rapidly. The measured values of temperature were corrected for interference of the thermometer itself and for cooling of the test tubes while measuring. These corrections were taken into account for tem-

peratures of 27–40°C. The room temperature for all measurements was  $23 \pm 1.5^\circ\text{C}$ . The procedure of temperature measurement was formalized and followed each time.

The total power, absorbed by the unit mass of the sample was calculated by the equation [10]:

$$W_{a,m} = \frac{c_p \Delta T_a}{t} \quad (1)$$

where  $W_{a,m}$  is the apparent power absorbed by 1 g of water sample (W/g),  $c_p$  is the specific heat capacity at the constant pressure ( $\text{J g}^{-1} \text{ deg.}^{-1}$ ),  $\Delta T_a$  (deg.) is the difference of the final and the initial temperatures, corrected as described above, and  $t$  is time of irradiation (seconds). We assumed, that the material of the test tubes does not absorb the electromagnetic field. Heat transfer from the sample during electromagnetic exposure is not taken into account; the magnitude of  $c_p$  was assumed to be invariable with temperature and equal to  $4.18 \text{ J g}^{-1} \text{ deg.}^{-1}$  [27]. It was also assumed that the capability of samples to absorb electromagnetic energy does not depend on the temperature of the sample. For 5-ml samples  $W_{a,m} = 0.22 \pm 0.02$ , for 2.5-ml samples  $W_{a,m} = 0.11 \pm 0.02$  (W/g) ( $n=5$  for 0.95 probability).

The ability of water samples to absorb the electromagnetic field is strongly dependent on the presence of dissolved electrolytes [10]. Adding neutral electrolytes (e.g. sodium chloride) to water samples is also one of the standard methods to rise the pre-concentration degree in SPE (so-called 'salting-out effect'). The power absorbed by 10 g/l sodium chloride aqueous solution was measured for 2.5- and 5-ml samples in the test and in the filled cartridges. In the last case the solution was pumped with a flow-rate of 1.4 ml/min, and the outlet temperature was measured out from the shield. Corrected for cooling in the connection tubings it was  $40 \pm 1^\circ\text{C}$ . For the 5-ml NaCl solution samples  $W_{a,m} = 1.27 \pm 0.06$  W/g, and for 2.5-ml samples  $W_{a,m} = 0.73 \pm 0.05$  W/g. For experiments with NaCl solutions pumped through the cartridges the apparent absorbed power was calculated according to Eq. 2, derived from Eq. 1:

$$W_A = C_p \Delta T_a F \quad (2)$$

Here  $W_A$  is the apparent power absorbed by the

cartridge with the pumped solution (W),  $F$  is the solution flow-rate in g/s. For this flow system  $W_a = 1.5 \pm 0.2$  W. This source of heat is not very large, and it was possible to maintain the average effluent temperature at  $24 \pm 2^\circ\text{C}$  with the help of a special water-cooled jacket. The variation of sodium chloride concentration in the range of 2–10 g/l did not show a difference in the efficiency of the power absorption.

The geometrical location of the cartridge in the centre of the coil cavity, the anode current of the generator, and the effluent temperature were the parameters maintained constant.

## 2.5. Procedure

The cartridges prepared as described above and containing octadecyl bonded silica, Tenax GC or non-bonded hydrophilized silica were activated by rinsing with 2 ml of methanol followed by 1 ml of pure water. The in this way conditioned cartridges were used for breakthrough, desorption or overall recovery experiments. To measure a breakthrough curve aqueous solutions of analytes were pumped through the bed at an adequate flow-rate and effluents were collected in glass vials. Optical density of each 1.5-ml portion of effluent was measured at the wavelength of maximal optical absorption (254 nm for benzene, 277 nm for naphthalene and 272 nm for phenol). As some part of the solutes was adsorbed by connections, actual concentration at the inlet of the cartridge was measured. To evaluate the influence of any experimental factor, the same cartridge was used to measure breakthrough or elution curves or overall recoveries with and without the factor. Each time the cartridges were rinsed with methanol to give eluates non-absorbing at corresponding wavelengths. Three series of experiments were carried out successively to confirm the influence of the flow-rate, salting-out effect, electromagnetic exposure of aqueous analyte solutions and analyte solutions containing 10 g/l of sodium chloride.

To measure the elution curves of the adsorbed analytes a portion of aqueous solution of benzene or naphthalene was pumped through the cartridge, optical absorption of collected effluent was measured

and the amount of adsorbed analyte was calculated. The solution, remaining in the cartridge was displaced by air with the syringe (approximately 5 ml), then the cartridge was connected to the syringe pump of the 'Milichrom-1A' liquid chromatograph, and methanol was pumped by 50- $\mu$ l portions. Each portion was collected in glass vials, 1.5 ml of methanol was added, and optical absorption was measured.

For overall recovery tests 2 ml of benzene solution (0.048 g/l) and 2 ml of naphthalene solution (0.041 g/l) were pumped through the column at a flow-rate of 0.6 ml/min, and the amount of the retained analyte was calculated. The influence of the following factors on the recovery was studied: admixture of 10 g/l sodium chloride and exposure of the cartridges to an electromagnetic field with solutions pumped. The adsorbed analytes were eluted from wet cartridges with 1.5 ml of methanol, collected in glass vials, and optical absorption of the eluates was measured.

### 3. Results and discussion

Benzene, naphthalene and phenol can be found in surface waters and are often analyzed with the SPE preconcentration step. The SPE recovery depends on both retention efficiency and elution efficiency. Measuring the breakthrough and elution curves is a reliable way to compare the efficiency of both processes. From the breakthrough curves the breakthrough volume can be calculated, which corresponds to the maximum volume of water which can be pumped through the cartridge without loss of the adsorbing solute. From the elution curve the minimum volume of organic eluent necessary to remove the retained analyte can be determined.

The breakthrough curves of the investigated compound on  $C_{18}$  silica and on Tenax GC are shown in Fig. 2 and Fig. 3. They were obtained for non-buffered distilled water of average pH 6.0 and represent mean values for three measurements. The relative standard deviation is commonly less than 7% for each system. The exact magnitude of breakthrough volume ( $V_B$ ) depends on the breakthrough level taken. In all the experiments the ratio of the

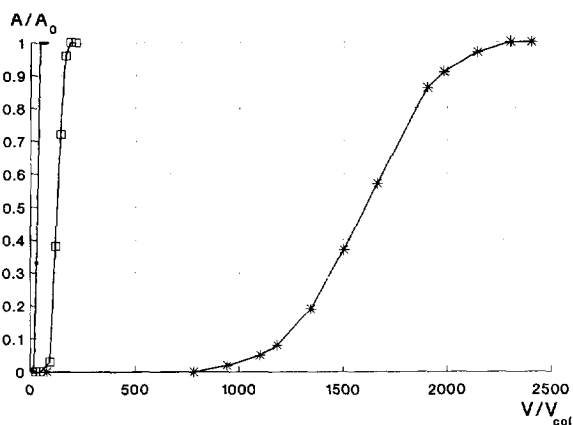


Fig. 2. Breakthrough curves of phenol ( $\cdot$ ), benzene ( $\square$ ), naphthalene ( $*$ ) aqueous solutions on Separon SGX RPS cartridges, measured as relative concentrations ( $c_r$ ) of the analytes at the outlet of the cartridge via relative pumped volume ( $V^*$ );  $c_r = A/A_0$ ;  $V^* = V/V_{col}$ . Here  $A$  is the effluent current optical absorption,  $A_0$  is the influent optical absorption,  $V$  is volume of the test solution pumped through the cartridge (ml),  $V_{col}$  is the cartridge volume (ml). Flow-rate 0.45 ml/min.

outlet relative concentration equal to 0.1 of the inlet one ( $c_r = 0.1c_0$ ) was taken as breakthrough, and the corresponding relative volume of pumped solution was taken as the breakthrough volume.

The breakthrough curves were measured for at

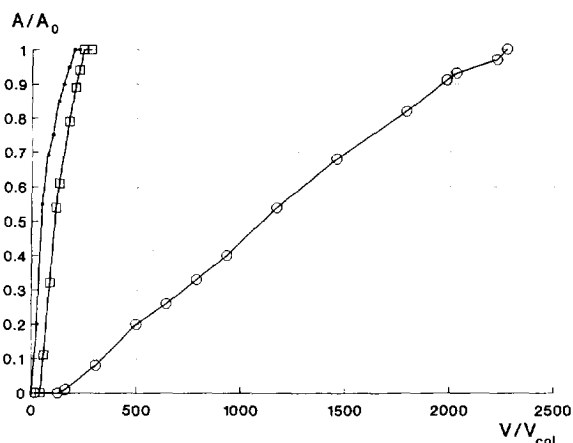


Fig. 3. Breakthrough curves of phenol ( $\cdot$ ), benzene ( $\square$ ), naphthalene ( $\circ$ ) aqueous solutions on Tenax GC cartridges. Flow-rate 0.45 ml/min; the designations are the same as in Fig. 2.

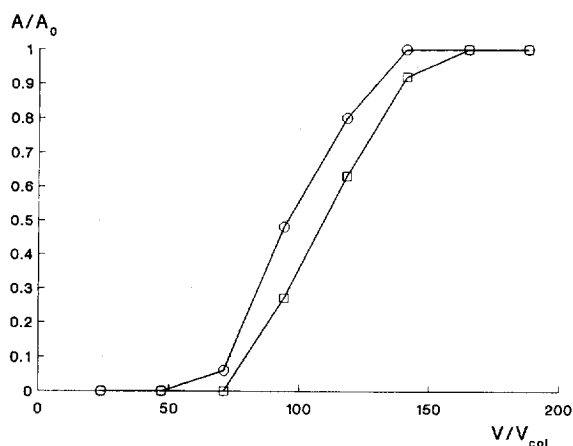


Fig. 4. Breakthrough curves of benzene aqueous solutions on Separon SGX RPS cartridges for different flow-rates; benzene concentration at the inlet 0.056 g/l, flow-rates (○)=2.25 ml/min, (□)=0.6 ml/min.

least two different concentrations of each analyte (0.048 and 0.011 g/l for benzene, 0.0041 and 0.0020 g/l for naphthalene, 0.0026 and 0.0072 g/l for

phenol). Their identity within the limits of inaccuracy showed that the stationary phase is not overloaded by the analyte [28]. The parameters of the breakthrough curve are dependent of the flow-rate. The breakthrough curves of the benzene aqueous solution at two different flow-rates are shown in Fig. 4. A similar effect of the flow-rate on retention was observed for all studied systems with  $C_{18}$  silica and Tenax GC. Therefore the flow-rate was maintained constant when the influence of other experimental factors was studied.

The influences of electromagnetic exposure of the cartridges with  $C_{18}$  silica and Tenax GC on retention volumes of benzene, naphthalene and phenol are represented in Table 1.

The capability of hydrophilized silica to retain phenol was tested additionally. The activation of surface sylanol groups by an electromagnetic field could be expected, analogously to promotion of esterification reaction in solutions [13,14]. The breakthrough measurements of aqueous phenolic solutions showed very low retention on non-modified silica and did not show any change of adsorption

Table 1

Influence of electromagnetic field irradiation on the retention of benzene, naphthalene and phenol by Tenax GC and Separon SGX RPS cartridges

Adsorbent and solvent	Analyte	Breakthrough volumes	
		Ordinary conditions	Irradiation with electromagnetic field
Separon SGX RPS aqueous solution	phenol	16 ± 1	15 ± 1
	benzene	71 ± 2	70 ± 3
	naphthalene	1180 ± 40	1120 ± 60
Separon SGX RPS NaCl 10 g/l	phenol	30 ± 1	30 ± 1
	benzene	68 ± 4	64 ± 5
Tenax GC aqueous solution	phenol	0	0
	benzene	34 ± 1	52 ± 4
	naphthalene	310 ± 6	580 ± 40
Tenax GC NaCl 10 g/l	phenol	0	0
	benzene	54 ± 3	150 ± 8
	benzene <sup>1</sup>		13 ± 1 <sup>1</sup>
	naphthalene	440 ± 20	900 ± 40

All the measured values of breakthrough volumes ( $n=3$  for 95% probability) are normalized on the magnitude of the volume of the used cartridge. Room temperature ( $24 \pm 2^\circ\text{C}$ ) was maintained for all measurements except those marked (<sup>1</sup>), which were made without external cooling, and effluent temperature was  $40 \pm 2^\circ\text{C}$ . Zero breakthrough volume for retention of phenol on Tenax GC meant that in the first 1.5-ml portion of pumped solution  $c_t > 0.1c_0$ .

with the field applied. It is evident that no covalent bonding occurs under the described conditions.

The data in the Table 1 show that the influence of an applied electromagnetic field and dissolved electrolytes on retention behaviour of Tenax GC and octadecyl bonded silica is different under the specified conditions. The breakthrough volumes were unchanged within the experimental error with application of the field for  $C_{18}$  silica, but noticeable effect was observed for Tenax GC. The ratios of  $V_B$  for irradiated and non-irradiated samples of aqueous solutions are 1.5 for benzene and 1.8 for naphthalene. The salting-out effect for benzene and naphthalene is also distinct for the last sorbent. Values of  $V_B$  in the NaCl solution are correspondingly 1.6 times larger than for the neat aqueous solution of benzene and 1.4 times larger for naphthalene. The effect of sorption enhancement by an electromagnetic field for NaCl solutions is of the same order. The ratios of the curve parameters are 1.8 for benzene and 2.0 for naphthalene.

This sufficiently high correlation of breakthrough volumes for benzene and naphthalene was not observed for phenol. For this analyte the salting-out effect was distinct for sorption on octadecyl bonded silica and was not observed on Tenax GC, moreover the retention of phenol by the both sorbents was not affected by the electromagnetic field irradiation. Phenol is a highly polar, ionizable compound, highly soluble in water, and its adsorption characteristics should be governed by additional equilibria in the volume of the water and on the sorbent surface if compared to aromatic hydrocarbons. Benzene and naphthalene are aprotic non-polar substances. The mechanisms of their adsorption on the surface of octadecyl bonded silica and Tenax GC are basically ruled by weak interactions (dispersive or dipole-induced dipole) and are not complicated by ionic or hydrogen bonding.

Kubrakova et al. [19] have proposed that a polymeric sorbent can undergo mechanical wrecking and/or some chemical cleavage with generation of additional active adsorption sites when exposed to a microwave electromagnetic treatment. In order to check whether this effect takes place in the studied system, the retention parameters of the cartridge with Tenax GC, preliminary exposed to an electromag-

netic field for 60 min with pure water pumped through it, were compared to the parameters of the cartridge without such exposure. As no differences in shape of breakthrough curves were found for aqueous solutions of benzene, it is reasonable to conclude that the adsorption process in dynamics is influenced by the field rather than bulk properties of the sorbent.

A possible reason for the adsorption process on Tenax GC under electromagnetic exposure could be the penetration of benzene and naphthalene molecules deep in the volume of polymeric support, forced by the electromagnetic field. If this process takes place, some difference in the form of the elution curve for exposed and non-exposed cartridges could be expected. To check this hypothesis the elution curves of naphthalene adsorbed with and without the field applied were obtained by the procedure similar to that described in [29].

The elution curves in Fig. 5 demonstrate that the form of the curves is not dependent on the amount of previously adsorbed naphthalene. Moreover the form of the curve was the same independently of the adsorbing and eluting technique, i.e. with or without exposure of the cartridge to an electromagnetic field.

Overall recoveries were determined for benzene and naphthalene adsorbed under different conditions. The values were 95–100% and irradiation by the field did not cause substantial change in SPE recoveries.

The fact that elution curves and recoveries are equal regardless of the adsorption conditions disproves the supposition that analyte molecules can be forced by an electromagnetic field to penetrate in the volume of Tenax GC.

A reasonable approach to understanding the different adsorption behaviour of Tenax GC compared to  $C_{18}$  silica under the studied conditions is the concept of film diffusion proposed by Pankow et al. [30]. It is generally accepted that poor mass transport between the water and the stationary phase is responsible for the slower rate of establishing the equilibrium of the adsorption–desorption process for Tenax GC as compared to octadecyl bonded silica. The authors of the above concept have obtained strong evidence that diffusion of analyte molecules through the solvent layer near the solid surface  $l$  prior to interaction is rate-determining in the adsorption process from

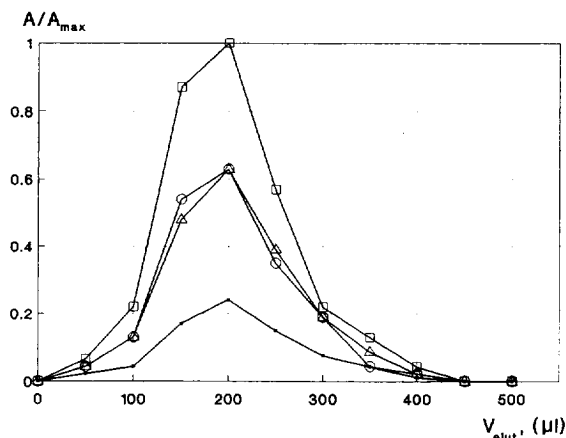


Fig. 5. Elution curves from Tenax GC cartridges, measured as naphthalene concentration in methanolic effluent fractions; (○) =  $3.2 \times 10^{-5}$  g of adsorbed naphthalene without electromagnetic treatment; (•) =  $1.2 \times 10^{-5}$  g of adsorbed naphthalene without electromagnetic treatment; (□) =  $4.1 \times 10^{-5}$  g of adsorbed naphthalene, adsorption with electromagnetic treatment; (△) =  $3.2 \times 10^{-5}$  g of adsorbed naphthalene, adsorption without the field applied, elution with electromagnetic treatment.

water onto Tenax GC. Supposing a perfect sink the following equation for the analyte concentration in the effluent ( $c_e$ ) was proposed [30]:

$$c_e = c_i \exp\left(-\frac{3D(1-p)t'}{2prl}\right) \quad (3)$$

where  $c_i$  is the influent concentration of the analyte,  $D$  is the diffusion coefficient,  $p$  is porosity of the bed,  $t'$  is the residence time of the analyte molecules in the bed,  $r$  is the sorbent particle radius. According to this concept, at least for the starting part of the breakthrough curve, when the full fixing of analytes takes place, only two parameters could be affected by the electromagnetic treatment:  $D$  and  $l$ . As Eq. 3 includes the ratio of this two parameters, the question remains which one (or both?) is varied.

As concerns adsorption onto bonded silica the film diffusion is not the rate-determining stage of the process. That is why the effect of electromagnetic irradiation is negligible.

The mechanism of electromagnetic field action (thermic or non-thermic) is not still clear. On the one hand measuring of breakthrough curves performed with an electromagnetic treatment without cooling,

approximately at 40°C (see Table 1) showed the decrease of benzene retention. This tendency is reverse to that found for the experiments at room temperature. On the other hand the measured temperature of the effluent is the volume-mean value, whereas local microscale overheating is usually supposed to be the reason of reaction rate enhancement in microwave irradiated systems [10,11]. It should be mentioned here that special, sufficiently complicated experiments are necessary to distinguish whether overheating on the molecular scale or deviation of volume properties of water in an electromagnetic field takes place.

#### 4. Conclusion

For the three sorbents tested [octadecyl bonded silica, poly-(2,6-diphenyl-*p*-phenyleneoxide) (Tenax GC), and hydrophilized silica], only retention of aromatic hydrocarbons, benzene and naphthalene on cartridges with Tenax GC is influenced by a radio high-frequency electromagnetic treatment. The breakthrough volumes increased in the presence of the electromagnetic field, and cooperative action of the field and the salting-out effect enlarged them by a factor of 1.5–4.5, making this sorbent beneficial for analyte preconcentration in HPLC. No effect of electromagnetic treatment on elution of the retained analytes by methanol was found.

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