

Cevdet Akbay¹
 Isiah M. Warner¹
 Shahab A. Shamsi²

Electrokinetic chromatography of twelve monomethylbenz[a]anthracene isomers using a polymerized anionic surfactant

¹Department of Chemistry,
 Louisiana State University,
 Baton Rouge, LA, USA

²Department of Chemistry,
 Georgia State University,
 Atlanta, GA, USA

A method for the separation of twelve monomethyl-substituted benz[a]anthracene isomers using poly-(sodium undecylenic sulfate) (poly-SUS) surfactant by means of electrokinetic capillary chromatography (EKC) is described. Several parameters such as concentration of acetonitrile (ACN), pH, as well as applied voltage were studied to optimize the EKC separation. ACN at a concentration of 35% v/v, 12.5 mM phosphate-borate buffer, 30 kV with 0.5% w/v poly-SUS at a pH of 9.5 provided a resolution of a mixture of nine out of twelve methylbenz[a]anthracene (MBA) isomers in 50 min. The results of this study suggest that molecular length of MBA rather than length-to-breadth ratio plays an important role in the elution order of some isomers.

Keywords: Electrokinetic chromatography / Polymerized surfactant / Methylbenz[a]anthracene isomers / Carcinogenic compounds
 EL 3218

1 Introduction

Recently, polycyclic aromatic hydrocarbons (PAH) have evoked considerable attention [1–5]. PAHs and their alkylated derivatives are well known as serious environmental contaminants and some are believed to contribute to the incidence of cancer in living organisms [6, 7]. Methyl-substituted PAHs such as monomethylbenz[a]anthracenes (MBA) are among the most biologically active alkylated aromatic compounds found in the environment [8, 9]. There are 12 possible positional isomers of MBAs (see Fig. 1), whose carcinogenicity depends mostly on the position of the methyl group on the benz[a]anthracene molecule. For example, 7-MBA has been found to be the most carcinogenic compound, followed by 6-, 8-, and 12-MBA, which have almost equal carcinogenic activity. The 9- and 11-MBA are the next most carcinogenic compounds; however, 1-, 2-, 3-, 4- and 5-MBA have low carcinogenicity [8, 10–12].

Different methods using gas chromatography (GC) on conventional nonpolar phases, and high-performance liquid chromatography (HPLC) have been published on the separation and identification of MBAs [13–16].

Correspondence: Professor I. M. Warner, Department of Chemistry, Louisiana State University, Baton Rouge, LA 70803, USA

E-mail: isiah.warner@chemgate.chem.lsu.edu

Fax: +504-388-3971

Abbreviations: ACN, acetonitrile; BGE, background electrolyte; EKC, electrokinetic chromatography; L/B, length-to-breadth ratio; MBA, monomethylbenz[a]anthracene; PAH, polycyclic aromatic hydrocarbon; poly-SUS, poly-(sodium undecylenic sulfate)

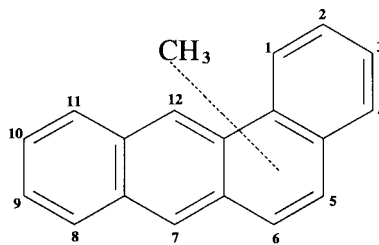


Figure 1. The chemical structure of MBA employed in this study. The numbers show the position of substituted methyl- groups on the benz[a]anthracene molecule.

Several liquid-crystalline alkene compounds based on the biphenylcarboxylate ester were evaluated as stationary phases for separation of MBAs in capillary GC, although some isomers were not resolved [13]. Garrigues and his co-workers [14] have studied the extracts of rock and air particulate matter by high-resolution Shpol'skii spectrometry (HRS). This technique allows identification of isomers of MBA based on the sharpening of the fluorescence emission spectra at low temperature in *n*-alkane polycrystalline frozen solution. However, before HRS analysis, isomers of MBA need to be isolated by use of a highly selective reversed-phase HPLC column. Wise *et al.* [15, 16] observed a linear relationship between the calculated length-to-breadth ratios (L/B) of PAHs, (including many mono- and dimethylated PAHs) and their reversed-phase LC retention. In general, they found an increase in HPLC retention with an increasing L/B of PAHs.

Capillary electrophoresis (CE) of nonionic analytes cannot be performed in a free solution due to the lack of electric charges on the analytes. This problem can be overcome by employing a charged additive that forms micelles

which can be used as a pseudostationary phase in fused-silica capillary columns [17, 18]. For example, sodium dodecyl sulfate (SDS) has been widely used as a pseudostationary phase with an aqueous electrolyte for the micellar electrokinetic chromatography (MEKC) of water-soluble analytes [19]. However, MBA isomers are highly hydrophobic neutral species that are difficult to separate using purely aqueous MEKC. Although a number of recent publications dealing with the use of binary mixtures of acetonitrile (ACN)-water and methanol-water and SDS for the separation of C₁₀–C₁₆ alkyl aryl phenones [20] and some PAHs [21] have been reported, its effectiveness as a pseudostationary phase remains problematic for the separation of highly hydrophobic PAHs. For these reasons, several different types of anionic surfactants such as bile salts [22, 23], as well as some double chain surfactants such as disodium 5,12-bis(dodecyloxymethyl)-4,7,10,13-tetraoxa-1,16-hexadecanedisulfate (DBTD) [24], sodium dioctyl sulfosuccinate (DOSS) [25], di(2-ethylhexyl)phosphate (DEHP) [26] have been used in MEKC for the separation of such compounds.

As an alternative, polymer surfactants [27–30] and micelle polymers [5, 21, 31–36] offer a simple and convenient way to organize surfactant monomers. Two current reviews cover the introduction, development and application of these polymerized surfactants in electrokinetic chromatography (EKC) in great detail [33, 34]. Recently poly-(sodium undecylenic sulfate) (poly-SUS) has been proposed as an alternative pseudostationary phase in EKC [5, 21, 32–36]. The monomer of SUS has a double bond at the end of the aliphatic chain with a sulfate head group. Thus, T-type micelle polymers (poly-SUS) are produced by γ -radiation-induced covalent linkage of the monomers at concentrations above the critical micelle concentration (CMC) [5]. In this manuscript, the feasibility of poly-SUS as a pseudostationary phase for EKC separation of twelve MBA isomers is demonstrated. To the best of our knowledge, there is but a brief report in the literature on the separation of only four MBA isomers using CE [37].

2 Materials and methods

2.1 Apparatus

A Beckman P/ACE Model 5510 CE instrument (Fullerton, CA) was employed in EKC separation of 12 MBA isomers. This instrument is equipped with a 0–30 kV high-voltage power supply, 200, 214, 254 and 280 nm selectable wavelength filters for UV detection, a liquid thermostated capillary cartridge, and System Gold software for system control and data acquisition. The fused-silica capillary

was obtained from Polymicro Technologies (Phoenix, AZ) and had the following dimensions: 57 cm total length, 50 cm to detection window, 51 μ m ID, and 361 μ m OD. The capillary was mounted in a cartridge and thermostated at 23°C by use of a fluoroorganic fluid. The detection time constant was 0.2 s.

2.2 Reagents

The scheme for the synthesis of poly-SUS is reported elsewhere [5]. The average molecular weight of the monomer units per polymer of the poly-SUS surfactant was estimated to be 32. This number was determined by use of the average molecular weight (8780), which was determined by analytical ultracentrifugation. The twelve isomers of MBA (each with a purity ranging from 94 to 99%) were a gift from Midwest Research Institute (Kansas City, MI)/National Cancer Institute Chemical and Physical Carcinogenesis Branch (Bethesda, MD). HPLC-grade ACN was obtained from Burdick and Jackson (Muskegon, MI). Disodium tetraborate (Na₂B₄O₇) and disodium hydrogen phosphate (Na₂HPO₄) were purchased from EM Science (Gibbstown, NJ). Sodium hydroxide (NaOH) was from Curtin Matheson Scientific (Houston, TX).

2.3 Preparation of EKC buffers and standards

For all EKC experiments, the final background electrolyte (BGE) consisted of a 12.5 mM mixture of Na₂HPO₄ and Na₂B₄O₇ buffered at various pH. The desired pH value was obtained by using either 1 M NaOH or 1 M HCl. The pH of each BGE was adjusted before addition of ACN and poly-SUS. Therefore, the pH values reported in this study are actually the pH before addition of ACN. The running EKC solutions were prepared by addition of various % w/v of poly-SUS surfactant to the appropriate % v/v of ACN and BGE. After ultrasonication for about 5–10 min, the final EKC buffers were filtered through a 0.45 μ m Nalgene syringe filter (Rochester, NY). All standard stock MBA solutions were prepared in ACN at a concentration of 1 mg/mL (ca. 4 mM). Since MBAs are carcinogens, stock solutions were handled in a ventilated hood and stored in a closed container in the refrigerator. Disposable latex gloves were worn while working with MBA standards and care was taken to dispose of the waste solutions appropriately.

2.4 Capillary electrophoresis procedure

A new capillary was prepared by use of a standard wash cycle of 1 M NaOH for 3 h at 50°C before use. The routine daily procedure also involved flushing the capillary with 0.1 M NaOH (10 min), triply deionized water (5 min), and

running EKC buffer (5 min). Between injections, the capillary was flushed for 3 min each with 0.1 M NaOH and EKC buffer. These procedures resulted in improved peak shape and minimized analyte adsorption on the capillary wall. At least four injections were made for each measurement under identical conditions. The RSD of migration time was not larger than 2.5% for the pH range of 7.0–9.5; however, the RSD at pH 9.75 and 10.0 was ca. 8% ($n = 3$). The molar concentration of 12 MBAs was ca. 0.3 mM, injected by pressure method (typically 1 s, 0.5 psi). The wavelength of 254 nm was selected for UV detection. The separation voltage was applied over a 0.17 min ramp to prevent any possible current breakdown.

3 Results and discussion

In our previous studies, 0.5% w/v of poly-SUS was found to be the optimum concentration for separation, as this was the best trade-off between resolution and analysis time for 16 priority PAHs [5, 27]. Similarly, Palmer *et al.* [21, 31] and Tanaka *et al.* [29, 30, 38, 39] have also used low concentrations of polymerized surfactants in their studies. In this work, various concentrations of poly-SUS, ranging from 0.1 to 1.0% w/v, were studied and 0.5% w/v was found to be the best concentration for the separation of MBA isomers (data not shown)

3.1 The influence of ACN concentration on the separation

In general, the use of organic solvents as a mixture with water alters the polarity and the viscosity of the bulk

electrolyte in MEKC or EKC. In addition, they may also increase the solubility of the analytes and decrease the partitioning between the solutes and the pseudostationary phase. As a consequence, the use of organic solvents is favorably applied to enhance the selectivity of MEKC or EKC by influencing the EOF and effective mobility of the analyte. Since the solubility of MBAs in a purely aqueous micellar solution is poor, ACN was added as an organic modifier to the BGE containing poly-SUS for MBAs separation. In our earlier EKC study, 40% v/v ACN and 0.5% w/v poly-SUS provided a baseline separation of all 16 priority PAHs in about 30 min [5].

With this in mind, we first tried 40% v/v ACN; however, resolution, especially that of later eluting MBA isomers, was not good. In contrast, 30% v/v ACN resulted in very long migration times (the first peak appeared at around 120 min at 30 kV). Thus, various % v/v of ACN fractions with a range of 33–40 were investigated. Dependencies of the relative migration (t_R/t_0) values of twelve MBAs on the fraction of ACN, measured at the optimized 0.5% w/v of poly-SUS, are shown in Fig. 2. As seen, when the volume fraction of ACN was raised from 33% to 40% v/v, there was a sharp decrease in migration times for all MBAs. In contrast, the migration time of the electroosmotic flow (*i.e.*, t_0) continued to increase in the same range (Fig. 2, inset). This trend of converging t_R/t_0 with a decrease in polarity of the bulk electrolyte is similar to the retention mechanism of reversed-phase HPLC. Note that an increase in the fraction of ACN in the poly-SUS cannot disrupt the micelle polymer. This is because the covalent linkage formed between the monomers prevents the

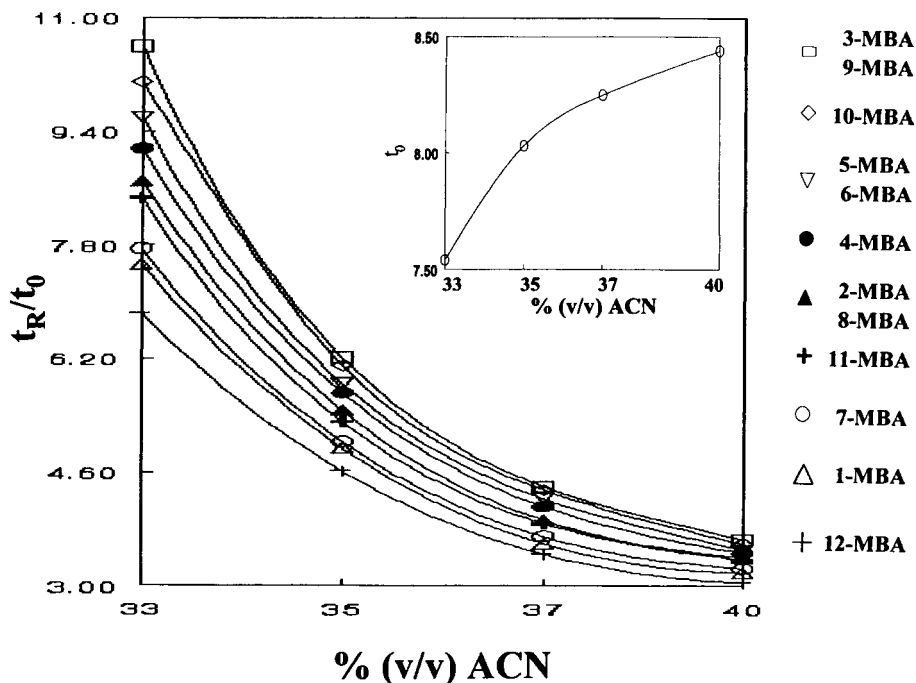


Figure 2. Relative migration (t_R/t_0) of the twelve MBAs as a function of % v/v of ACN in 0.5% w/v of poly-SUS. The BGE consisted of 12.5 mM each of Na_2HPO_4 and $\text{Na}_2\text{B}_4\text{O}_7$ at pH 9.5. A power of +30 kV was applied for separation. Inset: change in t_0 as a function of % v/v of ACN.

polymerized surfactant from dissociating into individual monomers. In addition, the partial specific volume of poly-SUS was found to be 0.7584 and 0.7685 in 35% v/v ACN and pure water, respectively. These data show that there is no significant change in polymer structure at a high volume fraction of ACN. Hence, the decrease in t_R/t_0 values of MBAs is probably related to a synergistic effect of reduced binding between the analyte and poly-SUS. The result obtained in this study is consistent with our previous findings with PAHs [5, 27]. In addition, Seifar *et al.* [20] and Palmer *et al.* [31] have observed similar behavior for the CE separation of hydrophobic analytes using ACN. Although the t_R/t_0 values for MBA isomers are too large at 33% v/v ACN, resolution suffered at or above 40% v/v ACN. Thus, 35% v/v ACN was chosen as optimum for the separation of the MBA isomers.

3.2 The influence of pH on the separation

The effect of the pH range 7.0–10.0 in 12.5 mM phosphate-borate buffer with 0.5% w/v poly-SUS, 35% v/v ACN was examined. Since the MBAs are electrically neutral and poly-SUS is fully charged in this pH range, the electrophoretic mobility of both the analyte and the pseudostationary phase should not be affected by a change in pH. However, if the pH of the bulk electrolyte is adjusted, there will be a change in the ionic strength of the electrolyte solution. We observed almost the

same current value of 29 μA at pH 7.0 and 8.0. As the pH of the buffer system was increased to 10.0 (using 1 M NaOH), current also increased to 48 μA as a result of higher ionic strength produced by Na^+ and OH^- as well as an increase in % of borate and phosphate. Such an increase in ionic strength causes the EOF to decrease due to a decrease in zeta potential. Our data are consistent with the study on ionic strength effects EOF reported by Vindevogel *et al.* [40, 41]. In addition, variations in ionic strengths may also affect the partition coefficient of the analytes between the aqueous and the micellar phase. Thus, an increase in pH from 7.0 to 10.0 provides a sensible increase in t_0 and t_R/t_0 values (see Fig. 3, inset A). However, note that both t_0 and t_R/t_0 increase much more rapidly between pH 9.1–10.0 as compared to pH 7.0–9.1. We believe that at higher pH values (pH 9.1 and above), changes in the conformation of poly-SUS provide an open and hydrophobic structure, which causes a stronger interaction with MBA isomers. Chu and Thomas [42] have also reported better separation at pH 10.0 than pH 9.0. They attributed this behavior to a more open structure of the polymer at higher pH. Separation at $\text{pH} \leq 9.5$ is advantageous in terms of shorter retention time compared to that obtained at higher pH values (pH 9.75 and 10.0). However, better resolution for neighboring peak pairs of MBA was gained at higher pH values as shown in inset B of Fig. 3.

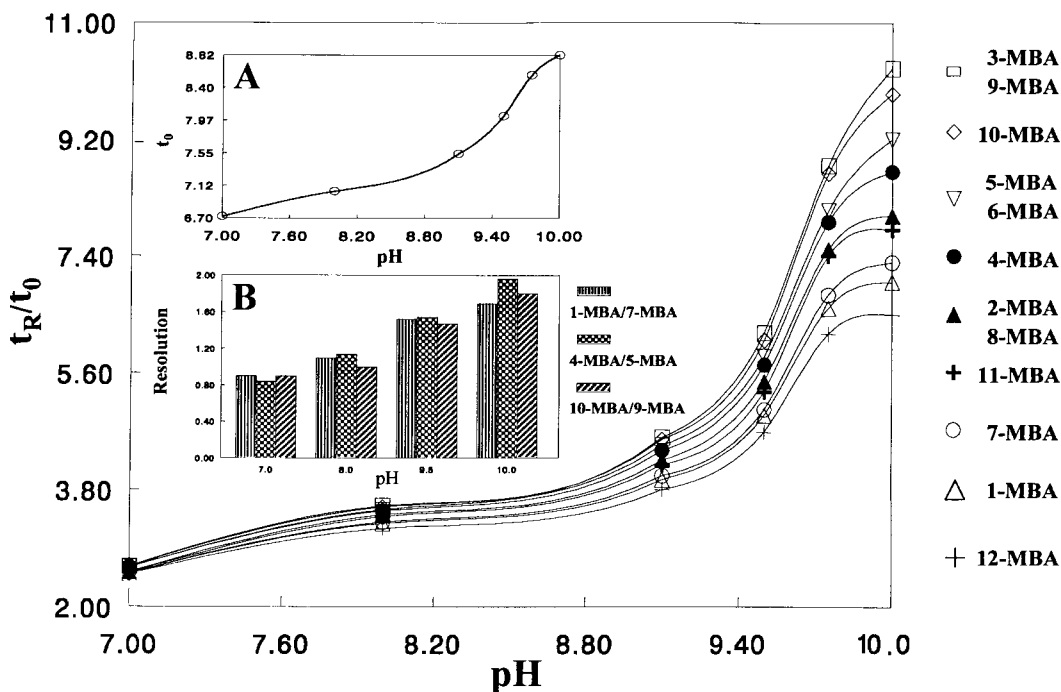


Figure 3. Relative migration (t_R/t_0) of MBAs as a function of pH. EKC conditions: 0.5% w/v of poly-SUS; 12.5 mM each of Na_2HPO_4 and $\text{Na}_2\text{B}_4\text{O}_7$, 35% ACN; +30 kV for separation; current, 29–48 μA . Inset (A): change in t_0 as a function of pH. Inset (B): resolution as a function of pH change.

3.3 Effect of applied voltage

According to theory, use of a higher voltage will produce greater theoretical plates and shorter migration times of sample components [43, 44]. Figure 4A shows the theoretical plate number as a function of applied voltage. There is a gradual increase in theoretical plate number as the voltage increased from 10 to 30 kV. As shown in the inset of Fig. 4A, there is an increase in current from 10 to 20 kV, then a slight deviation from linearity at 30 kV due to Joule heating effects. At lower voltage (10 kV), diffusion seems to be a dominant factor in band broadening, resulting in lower efficiencies. Moreover, at 10 kV, elution of all MBAs took more than 250 min, with a slightly better resolution compared with higher voltages (20 and 25 kV; (see Fig. 4B). A shorter elution time with slightly higher resolution between the adjacent peaks was observed at 30 kV than at 10 kV. Therefore, in this study, a maximum voltage of 30 kV was chosen due to faster separation.

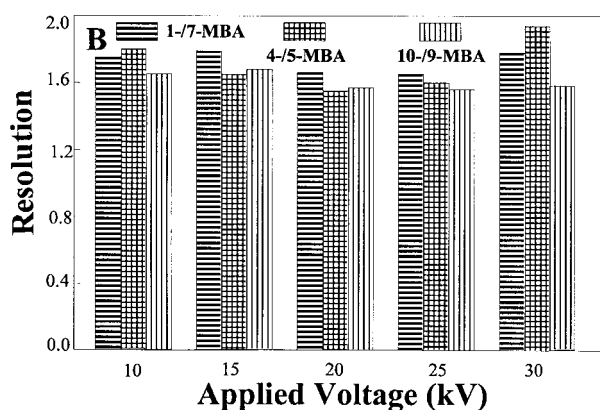
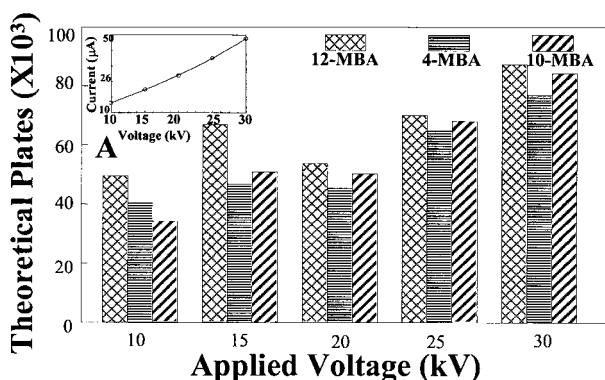


Figure 4. Effect of applied voltage on (A) theoretical plates (inset: current change vs. applied voltage); (B) resolution of MBAs. Separation conditions are the same as in Fig. 2 except a fixed 35% v/v ACN was used.

3.4 Optimized separation

Figure 5 shows the separation of the twelve MBA isomers, with optimized poly-SUS and 35% v/v ACN concentrations at pH 9.5. It is well known that in HPLC with polymeric stationary phases the elution order of most PAHs generally follows increasing L/B [4]. To investigate the relationship between t_R/t_0 and shape parameters (*i.e.*, length and L/B of MBA isomers; see Table 1), t_R/t_0 values of isomers were plotted against the length and L/B values.

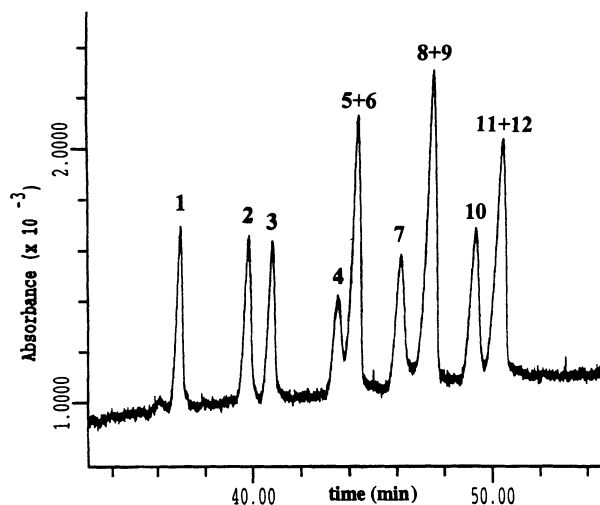


Figure 5. Electropherogram showing the optimized separation of twelve MBAs. Separation conditions are the same as in Fig. 3 except a fixed pH of 9.5 was used. Peak identifications: 1, 12-MBA; 2, 1-MBA; 3, 7-MBA; 4, 11-MBA; 5, 2-MBA; 6, 8-MBA; 7, 4-MBA; 8, 5-MBA; 9, 6-MBA; 10, 10-MBA; 11, 9-MBA; 12, 3-MBA.

Table 1. Comparison of t_R/t_0 and shape parameters (length and L/B) of methylbenz[a]anthracene isomers^{a)}

Compound	t_R/t_0	Length (Å) ^{b)}	L/B ^{b)}
12-Methylbenz[a]anthracene	4.62	13.82	1.54
1-Methylbenz[a]anthracene	4.94	13.76 ^{c)}	1.53
7-Methylbenz[a]anthracene	5.03	13.90	1.54
11-Methylbenz[a]anthracene	5.31	13.61 ^{c)}	1.48
2-Methylbenz[a]anthracene	5.47	13.92	1.51
8-Methylbenz[a]anthracene	5.47	13.94 ^{c)}	1.60
4-Methylbenz[a]anthracene	5.72	14.41 ^{c)}	1.65
5-Methylbenz[a]anthracene	5.85	13.92	1.45
6-Methylbenz[a]anthracene	5.85	13.93	1.41
10-Methylbenz[a]anthracene	6.10	14.28	1.59
9-Methylbenz[a]anthracene	6.22	15.04	1.73
3-Methylbenz[a]anthracene	6.22	15.05	1.73

a) Conditions are the same as in Fig. 5

b) Data taken from [4]

c) Exceptional MBAs

Although linear relationship with lower correlation coefficients was observed for both parameters, the correlation with L/B was much lower than that with the length (data not shown). It appears that the length of MBA plays an important role in elution order, more so than L/B using polymerized surfactant in EKC mode. Note that 1-, 7- and 12-MBAs eluted faster than other methyl derivatives. Our EKC data are also consistent with the earlier ultraviolet photoelectron studies published by Akiyama *et al.* [45] in which the electron densities at the 7- and 12-positions of MBA molecule were found to be very high compared to the other substitution positions. It appears that the higher electron density of 7- and 12-MBAs might cause electronic repulsion with the ionic head of poly-SUS, resulting in shorter migration times for these isomers.

3.5 Comparison of poly-SUS and SDS

The separation of the MBA isomers using SDS, the most widely used surfactant in MEKC, under similar BGE conditions (*i.e.*, 12.5 mM each of Na₂B₄O₇ and Na₂HPO₄ with 35% v/v ACN at a pH of 9.5) was not successful as compared with poly-SUS (data not shown). With 18.4 mM SDS (equivalent to 0.5% poly-SUS) an approximately 1.0 min elution window was generated and only three MBAs, out of twelve, were partially resolved. As the concentration of SDS is increased to 36 mM, the elution window was increased to 15 min, but only five MBAs were resolved in 72 min. Further increases in SDS concentration to 54 mM produced no elution of any MBA isomers even in 300 min. The poor resolution of MBAs with SDS can be explained by the disruption of the formation of SDS micelles at higher concentrations of organic solvent (in this case 35% ACN). In contrast, the structural integrity of poly-SUS is preserved at high contents of organic solvents. Thus, this comparison indicated the superiority of poly-SUS over SDS for the separation of MBAs.

4 Concluding remarks

In conclusion, a partial separation of MBA isomers can be successfully achieved by use of poly-SUS, a T-type micelle polymer with sulfate head groups, in the EKC mode in the presence of 35% v/v of ACN at a pH range of 9.1–10.0. These improved separations of MBA with poly-SUS are consistent with our previous study on 16 EPA priority PAHs [5]. In addition, note that spectroscopic data reported by Paleos *et al.* [46] indicated that hydrophobic analytes do not penetrate as deeply into the core of the polymerized surfactant as into normal micelle. Further studies such as the combined use of poly-SUS with β - and γ -cyclodextrins are planned to increase the peak resolution of coeluting MBAs.

This work was supported by a grant from National Science Foundation (Grant # CHE-9632916). The authors thank Dr. Harold Seifried (Chemical and Physical Carcinogenesis Branch, NCI, Rockville, MD), and Bonnie Charles (Midwest Research Institute, NCI Chemical Repository, Kansas City, MO) for providing the MBA standards used in this work. Isiah M. Warner also acknowledges the Philip W. West endowment for partial support of this research.

Received May 28, 1998

5 References

- [1] Yan, C., Dadoo, R., Zhao, H., Zare, R. N., *Anal. Chem.* 1995, 67, 2026–2029.
- [2] Dabek-Zlotorzynska, E., Lai, E. P. C., *J. Capil. Electrophor.* 1996, 3, 31–35.
- [3] Wise, S. A., Sander, L. C., May, W. E., *J. Chromatogr.* 1993, 642, 329–349.
- [4] Wise, S. A., Sander, L. C., in: Jinno, K. (Ed.), *Chromatographic Separations Based on Molecular Recognition*, Wiley-VCH, New York, NY 1997, Chapter 1, pp. 30–40.
- [5] Shamsi, S. A., Akbay, C., Warner, I. M., *Anal. Chem.* 1998, 70, 3078–3083.
- [6] Bartle, K. D., Lee, M. L., Novotny, M., *Analyst (London)*, 1977, 102, 731–788.
- [7] Grimmer, G., Jacob, J., Naujack, K. W., Dettbarn, G. F. Z., *Anal. Chem.* 1981, 309, 13–19.
- [8] Wislocky, P. G., Florentini, K. M., Fu, P. P., Yang, S. K., Lu, A. Y. H., *Carcinogenesis* 1982, 3, 215–217.
- [9] Hoffman, D., Schmeltz, I., Hecht, S. S., Wynder, E. L., *Polycyclic Hydrocarbons and Cancer*, Academic Press, New York 1978, Vol. 1, pp. 86–117.
- [10] Mohammad, S. N., *Indian J. Biochem. Biophys.* 1984, 21, 269–271.
- [11] Lamparczyk, H., Ochocka, R. J., *Chromatographia* 1986, 21, 409–412.
- [12] Morgan, D. D., Warshawsky, D., Atkinson, T., *Photochem. Photobiol.* 1977, 25, 31–38.
- [13] Bradshaw, J. S., Schregenberger, C., Chang, K. H.-C., Markides, K. E., Lee, M. L., *J. Chromatogr.* 1986, 358, 95–106.
- [14] Garrigues, P., Marniesse, M. P., Wise, S. A., Bellocq, J., Eward, M., *Anal. Chem.* 1987, 59, 1695–1700.
- [15] Wise, S. A., Bonnet, W. J., Guenther, F. R., May, W. E., *J. Chromatogr. Sci.* 1981, 19, 457–464.
- [16] Wise, S. A., in: Bjorseth, A. (Ed.), *Handbook for Polycyclic Aromatic Hydrocarbons*, Dekker, New York 1983, p. 183.
- [17] Terabe, S., Otsuka, K., Ichikawa, K., Tsuchiya, A., Ando, T., *Anal. Chem.* 1984, 56, 111–113.
- [18] Terabe, S., Otsuka, K., Ando, T., *Anal. Chem.* 1985, 57, 834–841.
- [19] Weinberger, R., Lurie, I. S., *Anal. Chem.* 1991, 63, 823–827.
- [20] Seifar, R. M., Kraak, J. C., Kok, W., *Anal. Chem.* 1997, 69, 2772–2778.

- [21] Palmer, C. P., Terabe, S., *Anal. Chem.* 1997, 69, 1852–1860.
- [22] Terabe, S., Shibata, M., Miyashita, Y., *J. Chromatogr.* 1989, 480, 413–420.
- [23] Otkusa, K., Terabe, S., Ando, T., *J. Chromatogr.* 1985, 332, 219–226.
- [24] Tanaka, N., Ishida, T., Araki, T., Masuyama, A., Nakatsuji, Y., Okahara, M., Terabe, S., *J. Chromatogr.* 1993, 648, 469–473.
- [25] Shi, Y., Fritz, J. S., *Anal. Chem.* 1995, 67, 3023–3027.
- [26] Akbay, C., Shamsi, S. A., Warner, I. M., *Electrophoresis* 1997, 18, 253–259.
- [27] Terabe, S., Ozaki, H., Tanaka, Y., *J. Chin. Chem. Soc.* 1994, 41, 251–257.
- [28] Yang, S. Y., Bumgarner, J. G., Khaledi, M. G., *J. High Res. Chromatogr.* 1995, 18, 443–445.
- [29] Tanaka, N., Nakagawa, K., Hosoya, K., Palmer, C. P., Kunugi, S., *J. Chromatogr. A* 1998, 802, 23–33.
- [30] Tanaka, N., Fukutoma, T., Hosoya, K., Kimita, K., Araki, T., *J. Chromatogr. A* 1995, 716, 57–67.
- [31] Palmer, C. P., Khaled, M. Y., McNair, H. M., *J. High Res. Chromatogr.* 1992, 15, 756–762.
- [32] Palmer, C. P., Terabe, S., *Kuromatogurafi* 1995, 16, 98–99.
- [33] Palmer, C. P., *J. Chromatogr. A* 1997, 780, 75–92.
- [34] Palmer, C. P., Tanaka, N., *J. Chromatogr. A* 1997, 792, 105–124.
- [35] Shamsi, S. A., Akbay, C., Warner, I. M., *Polymeric Anionic Surfactants for MEKC: Separation of 16 Priority Pollutant Polycyclic Aromatic Hydrocarbons*, Pittcon '97, Atlanta, GA, March 16–21, 1997, Poster 223P.
- [36] Shamsi, S. A., Mathison, S. M., Dewees, S., Wang, J., Warner, I. M., Pittcon '96, Chicago, IL, March 3–8, 1996, Poster 84P.
- [37] Ding W., Fritz, J. S., *Anal. Chem.* 1997, 69, 1593–1597.
- [38] Tanaka, N., Fukutome, T., Tanigawa, T., Hosoya, K., Kimota, K., Araki, T., Unger, K. K., *J. Chromatogr. A* 1995, 699, 331–341.
- [39] Tanaka, N., Iwasaki, H., Nakagawa, K., Hosoya, K., Araki, T., Patterson, D. G., *HPCE '97*, Anaheim, CA, 26–30 January, 1997.
- [40] Vindevogel, J., Sandra, P., *Anal. Chem.* 1991, 63, 1530–1536.
- [41] Vindevogel, J., Sandra, P., *J. Chromatogr.* 1991, 541, 483–488.
- [42] Chu, D. Y., Thomas, T. K., *Macromolecules* 1991, 24, 2212–2216.
- [43] Cohen, A. S., Paulus, A., Karger, B. L., *Chromatographia* 1987, 24, 15–18.
- [44] Li, S. F. Y., *Capillary Electrophoresis: Principles, Practice and Applications*, Elsevier Science Publishers, Amsterdam 1992, pp. 13–15.
- [45] Akiyama, I., Harvey, R. G., LeBreton, P. R., *J. Am. Chem. Soc.* 1981, 103, 6330–6332.
- [46] Paleos, C. M., Stassinopoulou, C. I., Malliaris, A., *J. Phys. Chem.* 1983, 87, 251–254.