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Review

Micelles as pseudo-stationary phases in micellar electrokinetic chromatography

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Abstract

This review article describes some general comments on micellar electrokinetic chromatography (MEKC) from the viewpoint of pseudo-stationary phases and presents a compiled list of surfactants used for MEKC, prepared from published papers. We tried to give comments on some typical surfactants from the practical point of view. © 1997 Elsevier Science B.V.

Keywords: Pseudo-stationary phases; Reviews; Micelles; Surfactants; Micellar electrokinetic chromatography

Contents

1. Introduction

The use of micelles in capillary electrophoresis (CE) was first published in 1984 [1]. In the paper, sodium dodecyl sulfate (SDS) was employed as a micelle-forming reagent under neutral conditions and some phenol derivatives were successfully separated, although the phenols were not ionized under the experimental conditions. 'Electrokinetic separation' was used for the technique in the first paper [1]

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according to a reviewer's recommendation. However, we were bearing in mind that the name of the technique should clearly show that the separation principle of the technique is based on chromatography. Therefore, in our second paper [2] on the technique, we used the term 'electrokinetic chromatography' and described a fundamental concept of the technique in terms of chromatography. The separation principle is applicable to separation techniques other than CE, provided that the micelle migrates at a velocity that is different from that of the bulk solution; e.g., size-exclusion chromatography with a micellar solution as a mobile phase can perform separation based on the differential partitioning to the micelle [3,4]. Therefore, we did not want to emphasize the word 'capillary' when we chose the name of the technique and we finally decided to use the name 'micellar electrokinetic chromatography' or MEKC [5,6], although the name, micellar electrokinetic capillary chromatography (MECC), was proposed by Burton et al. [7].

This review is on the micelle as the pseudo-stationary phase in MEKC and we intended to describe fundamental characteristics of the micelles or surfactants required in MEKC and the relationship between the molecular structure and selectivity. However, since most of these topics are found in the other articles in this thematic issue, we prepared a list of surfactants used in MEKC together with analytes separated with each surfactant and the separation conditions employed in each separation. Some comments are given on resolution, efficiency and selectivity in MEKC, in addition to typical examples of applications from the viewpoint of the effects of the micelle.

2. Separation characteristics in MEKC

2.1. Resolution

The separation principle of neutral analytes by MEKC is straightforward and the migration behavior is easily described according to chromatographic theory. The resolution equation in MEKC is given as [2]

$$R_s = \frac{N^{1/2}}{4}\left(\frac{\alpha - 1}{\alpha}\right)\left(\frac{k_2}{1 + k_2}\right)\left(\frac{1 - t_0/t_{mc}}{1 + (t_0/t_{mc})k_1}\right) \quad (1)$$

where N is the plate number, k_1 and k_2 are retention factors (capacity factors) of analytes 1 and 2, respectively, and t_0 and t_{mc} are the migration times of the bulk solution and the micelle, respectively. The selectivity term is the same as that in chromatography and the separation factor (α-value), which is defined as k_2/k_1, is determined by the combination of the micelle and the surrounding aqueous phase. The selectivity term is discussed in more detail in Section 2.3. The effect of the retention factor on resolution is not determined in a straightforward manner from Eq. (1), as discussed in several papers [2,8,9]. It should be noted that k is linearly related to the concentration of the micelle or surfactant in MEKC. The last term on the right-hand side of Eq. (1) originates from the limited migration-time window and the physical meaning has been shown by Zhang et al. [10] to be column availability. It can easily be drawn from Eq. (1) that the migration-time window or column availability is an important factor for improving resolution. To increase column availability, either an increase in the electrophoretic mobility of the micelle or a decrease in the electroosmotic mobility is required, as discussed elsewhere [11]. It should also be noted that column availability can be larger than unity, provided that the micelle and the bulk solution migrate in opposite directions [10,12]. The electroosmotic flow can be reduced under acidic conditions [12] or by hydrophilically coating the capillary [13–15]. Increasing the electrophoretic mobility of the micelle is not easy, but the octylglucoside–borate complex is a surfactant system where the column availability is altered by changing the electrophoretic mobility of the micelle, which can be increased by increasing the pH [16]. Another method used to expand the migration-time window is the use of a non-ionic/anionic mixed micelle [17]. The addition of a non-ionic surfactant, Brij 35, to the SDS solution affected electroosmotic and electrophoretic mobilities differently and, at a specific Brij 35 concentration, the micelle was stationary [17].

There are several different strategies for optimizing resolution in MEKC. The simplest way is to

follow a guide [18] but it is not always the shortest way to reach optimum separation. However, such a guide is instructive and helpful for finding preliminary experimental conditions. An analytical method to find the optimum condition was described starting from Eq. (1) [8,19]. Mathematically or theoretically optimum conditions can be found but, in practice, it is probable that several experiments will have to be performed before optimum conditions are achieved. Optimization based on chemometrics will be practical and straightforward. Several different methods were published; a Plackett-Burman design [20], overlapping resolution mapping methods [21–23].

It should be emphasized that Eq. (1) is only valid for neutral or uncharged analytes. Charged analytes exist as four different species in MEKC; free neutral, complexed (with the micelle) neutral, free charged and complexed charged. Therefore, even the equation for the retention factor is complex [24,25] and no resolution equation has yet been given. A computer-assisted optimization for the MEKC separation of charged analytes was developed [26] using a previously developed phenomenological model [24,25]. The gradient elution method was also developed for MEKC by Balchunas and Sepaniak [27] and Sepaniak et al. [28]. Gradient elution is not widely accepted, probably because it is a difficult technique to perform.

2.2. Efficiency

Band broadening in MEKC in relation to the plate number has been discussed in several papers [29–33]. A general consensus seems to have been reached that the cause of band broadening is due to longitudinal diffusion and plug size for hydrophilic or relatively hydrophobic analytes, having low-to-medium retention factors. This means that the plate number in MEKC is the same as or better than that in capillary zone electrophoresis (CZE), because the micelle has a lower diffusion coefficient than that of small molecules. However, for hydrophobic analytes with high retention factors, the cause of band broadening under high fields has not been clarified completely [33]. Kinetic or non-equilibrium dispersion will not be significant, nor will the polydispersity of the micellar size. As described by Yu et al. [33], to obtain optimal efficiency, the proper choice of buffer is necessary although the critical factors are unknown. A practical way to obtain a high efficiency is probably to try to change the buffer until satisfactory results are obtained.

2.3. Selectivity

Eq. (1) clearly illustrates that the effect of α on resolution is critical when the resolution is low. The separation factor, α, is determined by the micellar solubilization process and is influenced by the chemical nature of both the micellar phase and the surrounding aqueous phase. Various surfactant systems can be used as well as mixed micelles, possessing different solubilization characteristics, in order to control migration behavior and optimize selectivity. Besides micelles, other macromolecular structures, such as oligomers, micro-emulsions or dendrimers, can also be applied. The application of chiral surfactants or cyclodextrins enables enantiomeric separations to be performed.

Despite the ease of varying the composition of the micellar phase by rinsing the capillary with another solution, proper selection of a suitable surfactant system may be a difficult task. Yang et al. [34–36] studied chemical selectivity in MEKC using linear solvation energy relationships (LSER). They found that the size of the analyte molecule, or hydrophobicity, plays a major role in the solute interaction with all surfactant aggregates studied, as expected. In anionic surfactant systems, such as SDS and sodium cholate, hydrogen bond accepting basicity of the analyte was shown to be another important factor affecting selectivity, whereas dipolarity/polarizability and hydrogen bond donating acidity were shown to be of minor importance. On the other hand, in MEKC with an anionic fluorocarbon surfactant, lithium perfluorooctanesulfonate, a hydrogen bond donating acidity is predominant. A cationic surfactant, cetyltrimethylammonium bromide, shows a strong hydrogen bond accepting basicity. According to their study, hydrogen bond interaction is the predominant factor that determines chemical selectivity in MEKC. A more detailed explanation is given by Khaledi in this issue [37].

Retention indices, as introduced by Muijselaar et al. [38] and Ahuja and Foley [39], can also be applied to study selectivity in MEKC. Since the

retention index is a relative quantity, it is a good parameter to compare specific solute–micelle interactions and retention characteristics of different surfactant systems. Recently, it was demonstrated that retention indices facilitate the classification of solutes in terms of functional group selectivity [40], which is also briefly described in this issue [41].

A relatively new and unexploited area is the use of mixed micelles [40,42–45]. The addition of either an ionic or a non-ionic surfactant to a specific micellar system can alter the hydrophilic surface of the micelles significantly, even at low concentrations. As a consequence, different solubilization characteristics may be obtained which can be exploited to tune selectivity. Fig. 1 shows an example of the remarkable differences in selectivity for cold medicines among two surfactants, SDS, sodium trioxyethylene alkyl ether acetate (ECT) and a mixed micellar system of these two surfactants [42]. Timepidium bromide is used as a micelle marker. ECT showed much weaker interaction with the analytes than SDS. Fig. 2 shows the dependence of retention factors of guaifenesin and trimetoquinol on the composition of the mixed micelle [42]. Similar to the ECT micelle, the mixed micellar system showed weak interaction with the analytes. However, a significant difference

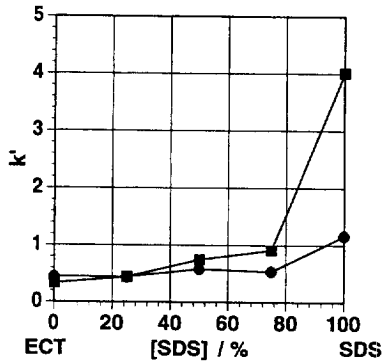

Fig. 2. Dependence of retention factors on the composition of the mixed micelle of ECT and SDS. (■) Trimetoquinol and (●) guaifenesin. Conditions are the same as in Fig. 1.

in selectivity can be observed. Little and Foley [43] reported on the use of mixed micellar systems of an ionic and a non-ionic surfactant, SDS and polyoxyethylene(23)dodecanol (Brij 35). Recently, it was demonstrated that the observed changes in selectivity with these mixed micellar systems may be attributed to different hydrogen bonding characteristics of the surfactants [40]. Bumgarner and Khaledi

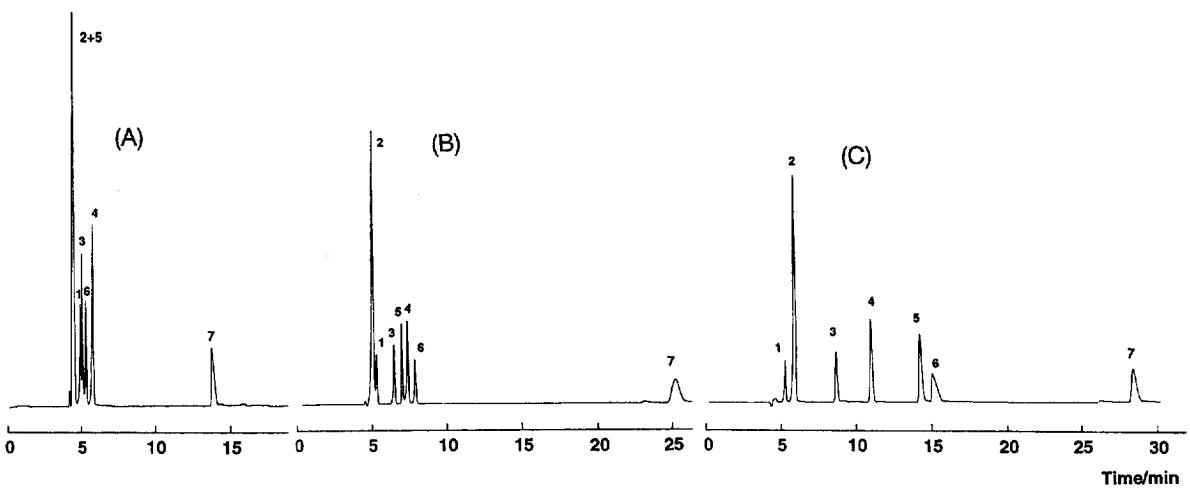

Fig. 1. Comparison of selectivity with SDS (C), ECT (A) and a mixture of the two surfactants (B). Peak identification: 1, acetaminophen; 2, caffeine; 3, guaifenesin; 4, ethenzamide; 5, trimetoquinol; 6, isopropylantipyrine and 7, timepidium bromide (micelle marker). Conditions: capillary, 65 cm (50 cm to the detector)×50 μm I.D. untreated fused-silica capillary; running solution, 50 m*M* ECT (A), 25 m*M* ECT+25 m*M* SDS (B) or 50 m*M* SDS (C) in 50 m*M* phosphate–100 m*M* borate buffer (pH 7.0); applied voltage, 20 kV; detection wavelength, 220 nm.

[44] reported on the use of mixtures of bile salt surfactants and/or SDS for the separation of corticosteroids. Mixed micellar systems containing a chiral surfactant enable the separation of enantiomers, as reported by several authors [46–50].

3. Micelles as pseudo-stationary phases in MEKC

3.1. Ionic surfactants

As shown in Table 1, SDS is the most widely used surfactant in MEKC. The purity of SDS is very high but still some minor homologous components can be detected by ESI–MS [277]. Critical micelle concentration (CMC) in pure water is 8.1 m*M* at 25°C [278], but the CMC differs from this value in other solvents. In general, the CMC decreases with the addition of electrolytes to the solution. For example, the CMC of SDS in 100 m*M* phosphate–50 m*M* borate buffer (pH 7.0) is 2.9 m*M* at 25°C [279]. The Krafft point, under which temperature the solubility of the surfactant is lower than the CMC, is 16°C for SDS in pure water [278] and, hence, care must be taken not to let the temperature of the solution go below the Krafft point, especially during an overnight run. The counter-ion of the ionic surfactant also affects the selectivity significantly [61,280]. A comparison of three different counter-ions of dodecyl sulfate showed that the counter-ion influences the CMC, Krafft point and electrophoretic mobility of the micelle in addition to selectivity [280]. Therefore, it is recommended that the same ions are employed between the surfactant's counter-ion and buffer electrolytes. When the counter-ion of the surfactant is different from the buffer electrolytes, care must be taken to keep the same composition among a series of runs for high reproducibility. According to LSER studies [34–36], SDS is strongly hydrogen bond donating and, hence, it tends to incorporate hydrogen bond accepting analytes more than other surfactants. The relatively strong hydrogen bond donating character of SDS suggests that α-methylene hydrogens of SDS may be weakly acidic and are accessible to the analytes.

Several additives to the SDS solution were developed to improve the selectivity or resolution. The most popular additives are organic solvents and cyclodextrins (CDs). Organic solvents are mainly employed to decrease retention factors and to expand the migration-time window. As different organic solvents show different selectivities in reversed-phase high-performance liquid chromatography (HPLC), methanol and acetonitrile also show different selectivities in MEKC with SDS. Significant changes in selectivity were observed when a small amount of more hydrophobic organic additives were added to the SDS micelle, such as 1-hexanol, cyclohexanol and 2-hexanone [281–283]. These modifiers are mostly incorporated into the palisade layer of the micelle and influence the interaction between the micelle and analytes. CDs form another class of useful additives to improve selectivity, particularly for the separation of aromatic isomers and enantiomers. It should be noted that the use of CDs in MEKC (CD-MEKC) is capable of separating neutral enantiomers.

Although several anionic alkyl chain surfactants are commercially available, anionic surfactants other than SDS are less popular. Alkanesulfonate surfactants will not show significantly different selectivity from SDS [2], but they are more stable than alkyl sulfate at acidic or alkaline pH values. Sodium N-lauroyl-N-methyltaurate (LMT), ECT, sodium dioxyethylene lauryl ether sulfate (SBL) and sodium tetradecene sulfonate (OS-14) showed significantly different selectivities for some cold medicine ingredients [94]. Since these surfactants are industrial products, purity is not high. However, a wide choice of surfactants will be helpful for the method development of MEKC and it will be convenient for the analytical chemists working in this field if a kit of surfactants for MEKC becomes available.

Most cationic surfactants have an alkyltrimethylammonium group and their counter-ions are halides. Cetyltrimethylammonium bromide (CTAB) is the most popular cationic surfactant used in CE, mainly to modify the capillary surface, but it is not widely used as a micelle-forming surfactant, probably due to UV absorption in the short wavelength region and the generation of bromine in the anodic vial during electrophoresis. However, CTAB or the corresponding chloride (CTAC) will show signifi-

Table 1
Different micellar systems used in MEKC and reported in literature

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Anionic surfactants				
Sodium dodecyl sulfate (SDS)				
5-Hydroxymethyl-2-furaldehyde and 2-furaldehyde in fruit juice	100			[51]
AFMU in urine	70			[52]
Amoxycillin	200	in D_2O		[53]
Amoxycillin	100			[54]
Aniline derivatives	50	8 m*M* γ-CD		[55]
Anthracene derivatives	100	30 m*M* γ-CD + 5 *M* urea		[56]
Antiepileptics in plasma	50			[57]
Antiepileptics/naproxen	75–200			[58]
Antimalarials and metabolites	4–80	10% acetonitrile		[59]
Antipyretic analgesics	50			[60]
Aromatics	50	5–15% acetonitrile		[61]
Aromatics	75	100 m*M* hexanol/cyclohexanol/phenol		[282]
Aromatics	50	100 m*M* cyclohexanol		[283]
Aspoxicillin in plasma	100			[54]
Asulam herbicides	50			[62]
Barbiturates	50			[63–65]
Barbiturates in serum/urine	50			[63]
Bases and nucleosides	100			[66,67]
β-Diketonato complexes of Co, Rh, Cr, Pt, Pd	20/100			[68]
Beer bitter acids	40			[69]
Benzene derivatives	50			[38]
Benzene derivatives	100	0–1 *M* methanol/1-propanol/1-butanol/1-pentanol/1-hexanol		[70]
Benzo(*a*)pyrene-adducted DNA	10			[71]
Benzodiazepines	50	20 m*M* γ-CD + 2 *M* urea + 1% THF		[72]
Benzodiazepines in human urine	75	5% methanol/2.5–10% isopropanol/2.5–10% acetonitrile		[73]
Benzothiazole/sulfonamides	50	20% methanol		[74]
Bioactive peptides	50			[65]
Bupivacaine in drain fluid/antipyrine in plasma	50	2% propanol		[75]
Caffeine metabolites in human urine	70			[76]
Cardiac glycosides	25–50	10–20 m*M* γ-CD/7 *M* urea		[77]
Cardiovascular drugs	50	15% acetone		[78]
Catecholamines	20/100			[79]
Catechols/catecholamines	10/20/80			[80–83]
CBI-amino acids	50	10 m*M* β-CD		[84]
CBQCA-amino acids	50			[85]
Cephalosporins	200			[86]
Cefpiramid in plasma	10			[87,88]
Barbiturates	50	30 m*M* γ-CD + 40 m*M* sodium D-camphor-10-sulfonate	chiral	[89]

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Chlorinated benzenes	100	40 m*M* γ-CD		[90]
Chlorinated phenols	100			[91]
Cicletamine	110	25 m*M* β-CD + 10% acetonitrile		[92]
Codeine and by products	40			[93]
Cold medicines	100			[94]
Corticosteroids	50	6 *M* urea		[95]
Corticosteroids	50	4 *M* urea + γ-CD		[96]
Creatinine in plasma/urine	50			[97]
Cyanobacterial toxins	10			[98]
Dabsyl-amino acids	5–10	50% acetonitrile		[99,100]
Dabth-amino acids	10	40% acetonitrile		[101]
Dansyl derivatized bases	45			[102]
Dansyl-amino acids	40/100/103			[103–105]
Dansyl-amino acids in skin	100–180			[106]
Dansyl-DL-amino acids	20	N,N-didecyl-L-alanine Cu(II)complex	chiral	[67]
Dansyl-DL-amino acids	100	60 m*M* γ-CD	chiral	[103]
Dansyl-DL-amino acids	100	50 m*M* β-CD + 10 m*M* γ-CD	chiral	[107]
Dimethylnaphthalenes	100	70 m*M* γ-CD + 2 *M* urea		[107]
Diuretics	42			[108]
DNPH-amino acids	100			[109]
Drugs of abuse in urine	75			[110,111]
Ecdysteroids	20	5% methanol		[112]
Estrogens	50	20% methanol		[113]
Explosives	25/50	0–20% acetonitrile		[114–117]
FITC-amino acids	75/100			[118,119]
Flavonoids	20/42/50			[120,21,121]
Flavonol glycones	30			[122]
Flavonol-2-*O*-glycosides	60			[123]
Flavonol-glycosides	50			[124]
Flavonones/flavonols/flavones	50			[125]
Fluorescamine-derivatized amino acids	100			[118]
FMOC-amino acids	25/100			[118,126]
Forensic drugs	100	20% methanol		[127]
GITC-DL-amino acids (diastereomers)	200		chiral	[128]
Glycyrrhizin/peoniflorin/ephedrine	100			[129]
Haematoporphyrin chelates	50			[130]
Heroin and impurities	45	β-CD-SBE + 10% acetonitrile		[131]
Hop bitter acids	25/40			[132,133]
Illicit drugs	75/85/100	0–15% acetonitrile		[134,111]
iso-α-Acids in beer	40			[135]
Lappoconitine	50	2–4% PEG		[136]
L-Marfey's reagent derivatized di- and tripeptides	200			[137]
L-Marfey's reagent derivatized-DL-amino acids	200		chiral	[137]
Mephenytoin enantiomers in human urine	95	40 m*M* β-CD + 8% 2-propanol	chiral	[138]

(*Cont.*)

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Metal complexes of acetylacetone	150	100 m*M* acetylacetone		[139]
Methadone metabolites in human urine	12.5	8% IPA		[140]
Methyl-substituted xanthines	150			[141]
Morphine analogues/caffeine/amphetamine in biological fluids	50			[142]
Morphine-3-glucuromide in human urine	75	10% acetonitrile		[143]
Motilins/insulins	50	15% acetonitrile		[144]
Mycotoxins	50	0–15% acetonitrile		[145]
Nitroaromatics	30			[146]
Non-steroidal anti-inflammatory drugs	25,40			[147,148]
Nucleic acid derivatives	50			[149]
Nucleosides	200–300			[66]
Nucleosides	150	1% methanol/20% methanol/1.0 *M* glucose		[150]
Nucleosides and nucleotides	200			[151,152]
Oligonucleotides	50	7 *M* urea+3 m*M* Zn(II)		[66,67,153]
OPA-amino acids	100			[118]
OPA-amino acids	50	15% methanol/2% THF		[154]
OPA-derivatized angiotensins	50	1% THF+15% methanol		[155]
OPA-DL-amino acids	150	5.5% methanol	chiral	[156]
PAH	100	70 m*M* γ-CD+5 *M* urea		[90]
PAH	50	30 m*M* β-CD+4 *M* urea		[96]
PAH	100	20 m*M* γ-CD+5 *M* urea		[107]
PAH	100	2 m*M* γ-CD		[157]
PAH	100	30 m*M* γ-CD+5 *M* urea		[158]
Par chelates of Co(III) Fe(III) Ni(II) Cu(II) Zn(II) Cd(II)	20			[159]
Paracetamol and antiepileptics in urine	75			[160]
Paracetamol in plasma	50			[161]
Penicillins/cephalosporins	150			[162,163]
Penicillins	50			[164]
Phthalates	10/50	20% methanol		[165,166]
Podophyllotoxin/kaempferol/quercetin	50	10–40% methanol/DMF		[167]
Polychlorinated biphenyls	110	73 m*M* β-CD +22 m*M* γ-CD +2*M* urea		[168]
Polycytidine	50	30 m*M* spermine		[169]
Polythymidilic acids	50	7*M* urea+5 m*M* Mg(II)/0.3 m*M* Cu(II)		[66]
Porphinato chelates	20	0.05 *M* imidazole		[170]
Porphyrins	20	8.2% DMF		[22]
PTH-amino acids	50			[171]
PTH-amino acids	100	4.3*M* urea		[95]
PTH-amino acids	33	10% acetonitrile		[172,173]
Purine derivatives	50			[15]
Purine in serum	75			[174]
Retinoic acid	25	20% acetonitrile		[175]
Substituted purines	50			[176]
THC-COOH in urine	75			[177]

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Theophylline metabolites	200			[178]
Thiopental in serum and plasma	50			[64]
Triazine herbicides	25			[179]
Trichlorobiphenyls	100	60 m*M* γ-CD+2 *M* urea		[90]
TRTC-amino acids	10			[180]
Porphyrins in urine	150			[181]
VB_6	10			[182]
VB_6 in urine	50			[7]
Vitamins	40			[104]
Water- and fat-soluble vitamins	30	1% 2-propanol/2–10 m*M* γ-CD		[183]
Water-soluble VBs	50			[184]
Water-soluble vitamins	50			[185,186,163,164]
Water-soluble vitamins	60	15% methanol		[187]
Water-soluble vitamins	100	13% acetonitrile		[188]
Sodium N-lauroyl-N-methyltaurate (LMT)				
Cold medicines	100			[94]
Penicillins/cephalosporins	150			[162,163]
Sodium trioxyethylene alkyl ether acetate (ECT)				
Cold medicines	100			[94,163]
Sodium dioxyethylene lauryl ether sulfate (SBL)				
Cold medicines	100			[94,163]
Sodium tetradecene sulfonate (OS-14)				
Cold medicines	100			[94,163]
Sodium octyl sulfate (SOS)				
Catecholamines	5–40			[79]
Magnesium dodecyl sulfate [$Mg(DS)_2$]				
Aromatics	50	4–14% acetonitrile		[61]
Disodium 5,12-bis(dodecyloxymethyl)-4,7,10,13-tetraoxa-1,16-hexadecanedisulphonate (DBTD)				
Naphthalene derivatives	10			[189]
Cationic surfactants				
Dodecyltrimethylammonium bromide (DTAB)				
Benzene derivatives	50			[38]
Hippurates	100			[190]
PTH-amino acids	50			[171]
Tricyclic antidepressants	25	0–10% methanol/0–4 *M* urea		[191]
Cetyltrimethylammonium bromide (CTAB)				
Aminoglycoside antibiotics	100	50 μl ml^{-1} FC 135		[192]
Amphetamines and related substances	25	11% DMSO+1% EA		[193]

(*Cont.*)

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Angiotensins	50			[194]
β-Blockers	10/15			[195–197]
Benzene derivatives	50			[38]
Cimetidine in serum	9.8			[198]
Cocaine and related substances	50	7.5% acetonitrile		[199]
Flavonoids	20–60			[200]
Glucosinolates/desulfoglucosinolates	50			[201]
Gonadorelin derivatives	20			[202]
Motilins/insulins	10/50	5–25% acetonitrile		[144]
Phenothiazines	10	50 μl ml^{-1} FC 135		[204]
Phenoxycarboxylic acids	50/60	4% 1-propanol		[205]
PTH-amino acids	50			[206]
Urea herbicides	31.2			[207]
Cetyltrimethylammonium chloride (CTAC)				
Inorganic anions (Br^-, NO_3^-, BrO_3^-, I^-, IO_3^-)	0.2/1/25			[203]
Tetradecyltrimethylammonium chloride (TTAC)				
Urea herbicides	27			[207]
Octyltrimethylammonium chloride (OTAC)				
Urea herbicides	50			[207]
Dodecyltrimethylammonium chloride (DoTAC)				
Urea herbicides	80			[207]
Decyltrimethylammonium chloride (DTAC)				
Urea herbicides	170			[207]
Tetrabutyl ammonium chloride (TBAC)				
Dansyl-DL-amino acids	1.5	50 m*M* β-CD + 10 m*M* γ-CD + 10% methanol	chiral	[107]
OPA-DL-amino acids	1.5		chiral	[156]
Tetrabutyl ammonium salt (TBA)				
Food additives (benzoic acid and sorbic acid)	2			[208]
Neutral surfactants				
Polyoxyethylene(20)sorbitanmonolaurate (Tween 20)				
Dansyl-amino acids	100			[209]
Angiotensin II analogs	200			[276]
Angiotensin II/motilin	0–250			[285]
Triton X-100				
Tetracycline antibiotics	0–0.03%			[210]
Octyl-β-D-glucopyranoside (OG)				
Herbicides	100			[211]
Herbicides/PAH/prometon herbicides	50			[16,212]

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Tricyclic antidepressants/angiotensins	30/80			[213]
Octyl-β-D-maltopyranoside (OM)				
Herbicides	100			[214,211]
Phenoxy acid herbicides	10–100		chiral	[215]
n-Octylsucrose (OS)				
Herbicides	100			[214,211]
Decanoyl-N-methylglucamide (MEGA 10)				
Herbicides/PAH/barbiturates	100			[211]
Bile acids and chiral surfactants				
Sodium cholate (SC)				
Aromatic choline esters	50	10% 2-propanol		[216]
Cardiac glycosides	25			[77]
Corticosteroids/alkyl *p*-hydroxybenzoates	100			[102]
Flavonoids	35	4–10% propanol/500 m*M* taurine		[200]
Ginsenoside Rb_1, Rb_2, Rc, Rd, Re, Rf, Rg_1	75	25% acetonitrile		[218]
Mycotixins	50	0–15% acetonitrile		[145]
Sennoside A, B, naringin, emodin, honokiol, magnolol	50	40% acetonitrile		[219]
Urinary estrogens	75–90	2% acetonitrile/20% methanol		[220]
Cold medicines/corticosteroids/diltiazem related compounds	50–100			[163]
Sodium deoxycholate (SDC)				
Aflatoxins	50			[221,222]
Aflatoxins	50	5% acetonitrile		[223]
Alkyl *p*-hydroxybenzoates/benzothiazepin analogues	50			[102]
Binaphthyls	5–50	12% methanol		[224]
Mycotoxins	50			[145]
Sodium taurocholate (STC)				
Benzothiazepin analogues	50			[102]
Sennoside A	75			[225]
Sodium taurodeoxycholate (STDC)				
CBI-DL-amino acids	50	20 m*M* β-CD	chiral	[226]
Chiral drugs	50			[227]
Dansyl-DL-amino acids	50		chiral	[228]
Dansyl-DL-amino acids	50	20 m*M* β-CD	chiral	[229]
Diltiazem analogues	50			[230]
Pharmaceuticals	50	10–100 m*M* HP-β-CD	chiral	[231]
Phthalates	50	20% methanol		[232]
Trimetoquinol hydrochloride related compounds	50			[233]
Oligosaccharides	80			[234]

(*Cont.*)

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Sodium N-dodecanoyl-L-valinate (SDVal)				
N-(3,5)-Dinitrobenzoyl-*o*-isopropyl ester/derivatized amino acids	25		chiral	[235]
PTH-DL-amino acids	20		chiral	[6]
PTH-DL-amino acids	25	10% methanol/5 *M* urea	chiral	[236]
Alkoxyacylamino acids				
Benzoin enantiomers	10–60		chiral	[237]
Ephedrine enantiomers	50		chiral	[238]
(S)- and (R)-N-dodecoxycarbonylvaline (DDCV)				
Ephedrine enantiomers	50		chiral	[239]
Dodecyl β-D-glucopyranoside-6-phosphate				
Aromatics/dansyl amino acids	10		chiral	[212]
(R,R)-Diacetyltartaric acid monododecylamide sodium salt				
Polyaromatics	5		chiral	[217]
(R,R)-Diacetyltartaric acid monodecylamide monoethylamide sodium sulfonate				
Polyaromatics	15		chiral	[275]
Macromolecular pseudo-stationary phases				
Butyl acrylate–butyl methacrylate–methacrylic acid copolymer (BBMA)				
Benzene/naphthalene derivatives	2%			[240]
Methyl methacrylate–ethyl acrylate–methacrylate acid copolymer (Elvacite 2669)				
PAH	2%	50% methanol		[241]
Poly(sodium 10-undecylenate) (polySUA)				
Alkylphthalates/PAH	5	20–40% acetonitrile		[242]
Alkylphthalates	5	0–45% acetonitrile		[243]
Poly(sodium N-undecylenyl-L-valinate) (poly(L-SUVal))				
1,1′-Bi-2-naphtol	0.02–0.5%			[244]
Poly(sodium 10-undecenyl sulfate) (polySUS)				
Cold medicines/substituted benzenes/naphthalenes	0.4–1%	40% acetonitrile/60% methanol		[245]
Dendrimers				
Alkylparabens				[246]
Benzene derivatives				[247]
Dansylated-amino acids		20% methanol		[248]

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
PAH		50–100% methanol		[249]
PAH		40–80% methanol		[250]
Resorcarenes				
PAH	3–12	50% acetonitrile + 6 *M* urea		[251]
Zwitterionic surfactants				
CHAPS				
Neurohypophyseal peptides	60			[252]
PAPS				
Polymyxins	30			[253]
Microemulsions				
Anionic aromatic compounds				[254]
Antipyretic analgesics				[255]
Aromatic compounds				[256,257]
Aromatic compounds/cold medicines				[258]
Cationic aromatic compounds				[259]
Ephedrine enantiomers	0.5% (2*R*,3*R*)-di-*n*-butyl tartrate		chiral	[260]
Hop bitter acids				[261]
Detones/β-di-ketones				[262]
Phenylureas				[263]
Steroids				[264]
Water- and lipid-soluble vitamins				[265]
Mixed surfactant systems				
Alkyl phenyl ketones	20 SDS + 10–60 Brij 35			[17]
Amphetamines and related substances	12 SDS + 25 Tween 20			[266]
Antiepileptics in serum	75 SDS + 5/10 Brij 35	0–5% methanol		[267]
Aromatics	20 SDS + 25–70 Brij 35			[39]
Aromatics	5 SDS + 50–125 SB12			[39]
Benzene derivatives	25 SDS + 10–50 Brij 35			[268]
Cephalosporins	50 SDS + 40 TMAB			[269]
Chlorophenoxy acid herbicides	100 SDS + 1 Brij 35			[270]
Dansyl-DL-amino acids	30 glycyrrhetic acid + 50 octyl-β-D-glucoside + 10 SDS		chiral	[46]
Dinitrophenyl fluoride-amino acids	48 SDS + 20 TBA			[23]
Explosives	50 SDS + 12.5 SB12			[117]
Glycyrrhizin, peoniflorin, geniposide	25 SDS + 100 SC			[271]

(*Cont.*)

Table 1. *Continued*

Surfactant type Analytes	Concentration (m*M*)	Additives	Remarks	Reference
Ingredients in analgesic tablets	25 SC + 50 SDC			[272]
MFA in urine	2 SDS + 10 TMAB			[273]
N-(3,5)-Dinitrobenzoyl-*o*-isopropyl ester derivatized amino acids	12.5 SDVal + 25 SDS		chiral	[47]
Opium alkaloids	12 SDS + 25 Tween 20			[266]
PTH-amino acids	40 Brij 35 + 50/20 SDS			[43]
PTH-amino acids	40 SDS + 2.5 CTAB			[274]
PTH-DL-amino acids	50 SDVal + 30 SDS	0.5*M* urea + 10% methanol	chiral	[48]
PTH-DL-amino acids	75 SDGlu + 30 SDS	1*M* urea + 10% methanol	chiral	[49]
PTH-DL-amino acids	50 digitonin + 50 STDC	1*M* urea	chiral	[49]
PTH-DL-amino acids	30 β-escin + 30 SDS		chiral	[46]
PTH-DL-amino acids	25 digitonin + 50 SDS		chiral	[6]
PTH-DL-amino acids	75 DSer + 75 SDS	1 *M* urea + 20% methanol/20% IPA	chiral	[50]
Tetracycline antibiotics	Tween 20 + Tween 80			[210]
Tetracycline antibiotics	Triton X-100 + Brij 35			[210]
VB_1 and VB_{12}	50 SDS + 20 TAA			[269]

Names of the analytes are as much as possible according to the original references. Surfactant concentrations are in m*M*, unless noted otherwise.

'%' in additive concentrations means volume %.

'/' means 'and/or'.

AFMU, 5-acetylamino-6-formylamino-3-methyluracil; BBMA, butyl acrylate-butyl methacrylate-methacrylic acid copolymer; β-CD-SBE, β-CD sulfobutyl ether; Brij 35, polyoxyethylene(23)dodecanol; CBI, 1-cyano-2-substituted-benz[L]isoindole derivatized; CBQCA, 3-(4-carboxybenzoyl)-2-quinolinecarboxaldehyde derivatized; CD, cyclodextrin; CHAPS, 3-[(cholamidopropyl)dimethylamino]-1-propanesulfonate; CTAB, cetyltrimethylammonium bromide; CTAC, cetyltrimethylammonium chloride; dabsyl, 4-(dimethylamino)azobenzene-4″-sulfonyl; dabth, dimethylaminoazobenzene thiohydantoin; dansyl, 5-dimethylaminonaphtalene-1-sulfonyl; DBTD, disodium 5,12-bis(dodecyloxymethyl)-4,7,10,13-tetraoxa-1,16-hexadecanedisulphonate; DDCV, (*S*)- and (*R*)-N-dodecoxycarbonylvaline; DMF, N,N-dimethylformamide; DMSO, dimethyl sulfoxide; DNPH, N-2,4-dinitrophenylhydrazone derivatized; DoTAC, dodecyltrimethylammonium chloride; DSer, N-dodecanoyl-L-serine; DTAB, dodecyltrimethylammonium bromide; DTAC, decyltrimethylammonium chloride; EA, ethanolamine; ECT, sodium trioxyethylene alkyl ether acetate; Elvacite 2669, methyl methacrylate-ethyl acrylate-methacrylate acid copolymer; FC 135, fluorinated alkyl quaternary ammonium iodide; FITC, fluorescein isothiocyanate derivatized; FMOC, 9-fluorenylmethyl chloroformate derivatized; GITC, 2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl isothiocyanate derivatized; HP-β-CD, hydroxypropyl β-CD; IPA, 2-propanol; LMT, sodium N-lauroyl-N-methyltaurate; MEGA, 10 decanoyl-N-methylglucamide; MFA, 3-methylflavone-8-carboxylic acid; $Mg(DS)_2$, magnesium dodecyl sulfate; OG, octyl-β-D-glucopyranoside; OM, octyl-β-D-maltopyranoside; OPA, *o*-phthaldialdehyde derivatized; OS, *n*-Octylsucrose; OS-14, sodium tetradecene sulfonate; OTAC, octyltrimethylammonium chloride; PAH, polycyclic aromatic hydrocarbons; PAPS, 3-(N,N-dimethylhexadecylammonium)propanesulfonate; par, 4-(2-pyridylazo)resorcinol; PEG, polyethylene glycol; poly(L-SUVal), poly(sodium N-undecylenyl-L-valinate); polySUA, poly(sodium 10-undecylenate); polySUS, poly(sodium 10-undecenyl sulfate); PTH, phenylthiohydantoin; SB12, N-dodecyl-N, N-dimethylammonium-3-propane-1-sulfonic acid; SBL, sodium dioxyethylene lauryl ether sulfate; SC, sodium cholate; SDC, sodium deoxycholate; SDGlu, sodium N-dodecanoyl-L-glutamate; SDS, sodium dodecyl sulfate; SDVal, sodium N-dodecanoyl-L-valinate; SOS, sodium octyl sulfate; STC, sodium taurocholate; STDC, sodium taurodeoxycholate; TAA, tetraalkylammonium salt; TBA, tetrabutyl ammonium salt; TBAC, tetrabutyl ammonium chloride; THF, tetrahydrofuran; TMAB, tetramethyl; TRTC, tetramethylrhodamine thiocarbamyl derivatized; TTAC, tetradecyltrimethylammonium chloride; Tween, 20 polyoxyethylene(20)sorbitanmonolaurate; Tween, 80 polyoxyethylene(20)sorbitanmonooleate; VB, vitamin B.

cantly different selectivities from anionic surfactants. According to the LSER study [34–36], CTAB is both hydrogen bond donating and accepting. Therefore, the use of a cationic surfactant instead of SDS is a promising alteration to change the selectivity.

3.2. Non-ionic surfactants

Non-ionic surfactants themselves do not posses electrophoretic mobility and cannot be used as pseudo-stationary phases in conventional MEKC. However, non-ionic surfactant micelles are useful for the separation of charged compounds, especially for peptides with closely related structures [276,284]. Since the separation principle is the same as with ionic surfactants, we can classify the technique with non-ionic micelles as an extension of MEKC. This technique was successfully applied to the mass spectrometric detection of peptides separated by MEKC with non-ionic surfactants [285].

Non-ionic surfactants can also be employed as pseudo-stationary phases in MEKC with a combination of ionic surfactants. Most non-ionic surfactants have oxyethylene groups and, hence, mixed micelles of non-ionic and ionic surfactants show significantly different selectivities from the ionic surfactant micelle as described above. Some natural chiral surfactants are uncharged and were used as mixed micelles with SDS [6,46,49].

3.3. Macromolecular surfactants

Macromolecular surfactants or high molecular mass surfactants have several advantages over conventional low molecular mass surfactants. The CMC is essentially zero and, hence, precise micellar concentrations can be prepared irrespective of temperature and buffer composition. The constant micelle concentration will produce high reproducibility in migration time and peak area. We investigated the reproducibility in MEKC with butyl acrylate–butyl methacrylate–methacrylic acid copolymer (BBMA) in comparison with SDS. BBMA gave higher reproducibility in migration times than SDS, as expected, but lower reproducibility in peak area than SDS [286]. The lower reproducible of peak area was probably ascribed to the low chemical purity of BBMA, which caused a noisy baseline.

Zero CMC is also advantageous when we employ the partial filling technique in MEKC (PFMEKC), where a part of the capillary is filled with a micellar solution. When SDS is used in PFMEKC, the SDS micelle will break down into monomeric surfactant molecules and the boundary between the micellar zone and the aqueous zone tends to broaden. However, when a macromolecular surfactant is employed in PFMEKC, the boundary is kept sharp, because one macromolecular surfactant molecule usually forms a micelle. PFMEKC is one of the promising techniques for MEKC–MS, as described by Yang and Lee [287] in this issue. Another advantage of the zero CMC of macromolecular surfactants was shown in on-column sample concentration in MEKC [288,289]. In sample stacking mode in MEKC, the sample is dissolved in water and injected as a long plug. When a voltage is applied, sample stacking occurs at the boundary between the sample solution and the micelle solution through the higher velocity of the micelle in the sample zone, due to an enhanced field strength. During the stacking process, the micelle concentration is low in the sample zone because of the high velocity of the micelle. If the surfactant concentration is lower than the CMC in the sample zone, no stacking will occur. However, the macromolecular micelle can incorporate the sample components even at a low concentration. In fact, we were able to obtain a higher stacking efficiency with macromolecular surfactants than with SDS. To date, the problem with macromolecular surfactants is their low chemical purity.

Dendrimers [246–250] and resorcarenes [251] cannot be classified as micelles, but they have been shown to work as pseudo-stationary phases in EKC. Starburst dendrimers have completely symmetrical and highly branched structures and must be monodisperse. Modification of the end group of each branch of the dendrimers is possible and the modification is useful for altering the selectivity [250]. Although alkylated polyallylamines are not symmetrical compounds, they worked in a similar manner to the dendrimers in EKC [290]. These polymers were much easier to prepare than dendrimers, and showed high selectivity for aromatic compounds in a buffer containing a high concentration of an organic sol-

vent. One of the advantages of these polymer pseudo-stationary phases is their stability in high organic solvent-containing buffers as well as in macromolecular micelles.

3.4. Chiral surfactants

Bile salts are a group of natural and chiral surfactants having steroidal structures. Cholate and deoxycholate and their conjugates are useful in MEKC. Taurine conjugates can be used even in acidic buffers. Bile salts are not so useful as CDs for enantiomer separation. However, they can separate neutral enantiomers and MEKC will be more robust for the analysis of mixtures containing both chiral and achiral compounds. Most other chiral surfactants used in MEKC are natural or amino acid-derived ones and few newly developed chiral surfactants have been reported. It is very interesting that N-dodecyloxycarbonylvalinate (DDCV) showed superior chiral selectivity to sodium N-dodecanoylvalinate (SDVal) [239], although the difference in molecular structure is only a connecting group between the long alkyl group and the amino acid moiety; urethane or amide. DDCV is probably a stronger hydrogen bond acceptor than SDVal. Recently, some new types of chiral surfactants have been described; glucose-derived dodecyl β-D-glucopyranoside-6-phosphate [212] and tartaric acid-derived diacetyltartaric acid monodecylamide sodium salt and a related compound [217,275]. Although these surfactants are not widely applicable yet, more new chiral surfactants will be developed in the near future for enantiomeric separation by MEKC.

3.5. Others

Zwitterionic surfactants are not widely used in MEKC. However, zwitterionic surfactants will be interesting if they are used as a modifier of the micelle or in mixed micelles, because they should show significantly different selectivities from other types of surfactants.

Microemulsion (o/w, oil in water) was first employed as a pseudo-stationary phase in EKC by Watarai [262] and it was shown that microemulsions have very similar characteristics to those of micelles in MEKC. The efficiency is also as high as that obtained in MEKC, although microemulsions are supposed to be more polydisperse than micelles. Since microemulsions consist of four components, surfactant, hydrophobic organic solvent, a cosurfactant such as alcohol, and water or buffer, the electrophoretic mobility of the microemulsion depends on the content of the surfactant. In fact, the electrophoretic mobility of a microemulsion consisting of SDS, hexane, 1-octanol and buffer was significantly increased by increasing the content of SDS [258]. Although it was expected that the choice of organic solvent in the microemulsion significantly affected the selectivity, it was not the case for most analytes, as shown in Table 2, probably because the analytes were not incorporated into the core but were adsorbed or incorporated on the surface of the microemulsion [291]. The organic solvent will be in the core and surfactant and cosurfactant will be on the surface. Microemulsions are interesting pseudo-stationary phases to be studied in more detail in EKC.

Table 2
Retention factors, k, of six cold medicines in microemulsions containing different oils

SDS–oil–BuOH	Heptane	Allyl ether	Dipropyl ether
Caffeine	0.388	0.387	0.363
Acetaminophen	0.443	0.463	0.465
Guaifenesin	1.25	1.28	1.27
Trimetoquinol	1.75	1.72	1.85
Ethenzamide	2.02	2.23	2.23
Isopropylantipyrine	2.82	3.32	3.44
t_0	6.08	6.23	6.52
t_m	34.9	36.1	39.1
t_0/t_m	0.174	0.174	0.167

Microemulsion, ([SDS]:[oil]:[BuOH/100 mM)=(1:1:10) in borate–phosphate buffer (pH 7.0); capillary, 52 μm I.D., length 300 mm; separation voltage, 12 kV.

4. Conclusion

Although various kinds of surfactants have been used in MEKC as pseudo-stationary phases, SDS was employed in most cases, suggesting the superiority of SDS as the pseudo-stationary phase. However, it is essential to have several choices of surfactants to improve selectivity. Such surfactants should have different selectivities from each other

and they could be selected according to a systematic study, such as LSER or retention indices. Unfortunately, the present results of the LSER study or retention indices have not supplied enough information yet to cover a wide range of analytes. Nevertheless, we should take advantage of these studies to correctly choose a surfactant as the pseudo-stationary phase. We hope a set of surfactants with different selectivities will be commercially available for MEKC in the near future.

References

[1] S. Terabe, K. Otsuka, K. Ichikawa, A. Tsuchiya, T. Ando, Anal. Chem. 56 (1984) 111.
[2] S. Terabe, K. Otsuka, T. Ando, Anal. Chem. 57 (1985) 834.
[3] S. Terabe, H. Tanaka, K. Otsuka, T. Ando, J. Chromatogr. Sci. 27 (1989) 653.
[4] D.G. Heries, W. Bishop, F.M. Richard, J. Phys. Chem. 68 (1964) 1842.
[5] S. Terabe, Trends Anal. Chem. 8 (1989) 129.
[6] K. Otsuka, S. Terabe, J. Chromatogr. 515 (1990) 221.
[7] D.E. Burton, M.J. Sepaniak, M.P. Maskarinec, J. Chromatogr. Sci. 24 (1986) 347.
[8] J.P. Foley, Anal. Chem. 62 (1990) 1302.
[9] J. Vindevogel and P. Sandra, Introduction to Micellar Electrokinetic Chromatography, Hüthig, Heidelberg, 1992, pp. 141–145.
[10] L.-X. Zhang, Z.-P. Sun, D.-K. Lin, J. Chromatogr. A 655 (1994) 308.
[11] S. Terabe, N. Chen, K. Otsuka, Adv. Electrophor. 7 (1994) 87.
[12] K. Otsuka, S. Terabe, J. Microcol. Sep. 1 (1989) 150.
[13] S. Terabe, H. Utsumi, K. Otsuka, T. Ando, T. Inomata, S. Kuze, Y. Hanaoka, J. High Resolut. Chromatogr. Chromatogr. Commun. 9 (1986) 666.
[14] A.T. Balchunas, M.J. Sepaniak, Anal. Chem. 59 (1987) 1466.
[15] J.A. Lux, H. Yin, G. Schomburg, J. High Resolut. Chromatogr. 13 (1990) 145.
[16] J. Cai, Z. El Rassi, J. Chromatogr. 608 (1992) 31.
[17] E.S. Ahuja, K.R. Nielsen, J.P. Foley, E.L. Little, Anal. Chem. 67 (1995) 26.
[18] S. Terabe, J. Pharm. Biomed. Anal. 10 (1992) 705.
[19] K. Ghowsi, J.P. Foley, R.J. Gale, Anal. Chem. 62 (1990) 2714.
[20] J. Vindevogel, P. Sandra, Anal. Chem. 63 (1991) 1530.
[21] C.L. Ng, C.P. Ong, H.K. Lee, S.F.Y. Li, Chromatographia 34 (1992) 166.
[22] Y.J. Yao, H.K. Lee, S.F.Y. Li, J. Chromatogr. 637 (1993) 195.
[23] Y.F. Yik, S.F.Y. Li, Chromatographia 35 (1993) 560.
[24] M.G. Khaledi, S.C. Smith, J.K. Strasters, Anal. Chem. 63 (1991) 1820.
[25] J.K. Strasters, M.G. Khaledi, Anal. Chem. 63 (1991) 2503.
[26] C. Quang, J.K. Strasters, M.G. Khaledi, Anal. Chem. 66 (1994) 1646.
[27] A.T. Balchunas, M.J. Sepaniak, Anal. Chem. 60 (1988) 617.
[28] M.J. Sepaniak, D.F. Swaile, A.C. Powell, R.O. Cole, J. High Resolut. Chromatogr. 13 (1990) 679.
[29] M.J. Sepaniak, R.O. Cole, Anal. Chem. 59 (1987) 472.
[30] S. Terabe, K. Otsuka, T. Ando, Anal. Chem. 61 (1989) 251.
[31] J.M. Davis, Anal. Chem. 61 (1989) 2455.
[32] L. Yu, J.M. Davis, Electrophoresis 16 (1995) 2104.
[33] L. Yu, T.H. Seals, J.M. Davis, Anal. Chem. 68 (1996) 4270.
[34] S. Yang, M.G. Khaledi, Anal. Chem. 67 (1995) 499.
[35] S. Yang, M.G. Khaledi, J. Chromatogr. A 692 (1995) 301.
[36] S. Yang, J.G. Bumgarner, L.F.R. Kruk, M.G. Khaledi, J. Chromatogr. A 721 (1996) 323.
[37] M. Khaledi, J. Chromatogr. A, (1997) in press.
[38] P.G.H.M. Muijselaar, H.A. Claessens, C.A. Cramers, Anal. Chem. 66 (1994) 635.
[39] E.S. Ahuja, J.P. Foley, Analyst 119 (1994) 353.
[40] P.G. Muijselaar, H.A. Claessens, C.A. Cramers, Anal. Chem. 69 (1997) 1184.
[41] P.G. Muijselaar, J. Chromatogr. A, (1997) in press.
[42] K. Hirota and S. Terabe, unpublished data (1994).
[43] E.L. Little, J.P. Foley, J. Microcol. Sep. 4 (1992) 145.
[44] J.G. Bumgarner, M.G. Khaledi, Electrophoresis 15 (1994) 1260.
[45] S. Terabe, H. Ozaki, Y. Ishihama, Bunseki Kagaku 42 (1993) 859.
[46] Y. Ishihama, S. Terabe, J. Liq. Chromatogr. 16 (1993) 933.
[47] A. Dobashi, T. Ono, S. Hara, J. Yamaguchi, Anal. Chem. 61 (1989) 1984.
[48] K. Otsuka, J. Kawahara, K. Tatekawa, S. Terabe, J. Chromatogr. 559 (1991) 209.
[49] K. Otsuka, M. Kashihara, Y. Kawaguchi, R. Koike, T. Hisamitsu, S. Terabe, J. Chromatogr. A 652 (1993) 253.
[50] K. Otsuka, K. Karuhaka, M. Higashimori, S. Terabe, J. Chromatogr. A 680 (1994) 317.
[51] D. Corradini, C. Corradini, J. Chromatogr. 624 (1992) 503.
[52] D.K. Lloyd, K. Fried, I.W. Wainer, J. Chromatogr. 578 (1992) 283.
[53] G.N. Okafo, P. Camilleri, Analyst 117 (1992) 1421.
[54] H. Nishi, T. Fukuyama, M. Matsuo, J. Chromatogr. 515 (1990) 245.
[55] S. Takeda, S. Wakida, M. Yamane, A. Kawahara, K. Higashi, J. Chromatogr. A 653 (1993) 109.
[56] T. Imasaka, K. Nishitani, N. Ishibashi, Analyst 116 (1991) 1407.
[57] K.J. Lee, G.S. Heo, N.J. Kim, D.C. Moon, J. Chromatogr. 608 (1992) 243.
[58] A. Schmutz, W. Thormann, Electrophoresis 15 (1994) 51.
[59] R.B. Taylor, R.G. Reid, J. Pharm. Biomed. Anal. 11 (1993) 1289.
[60] S. Fujiwara, S. Honda, Anal. Chem. 59 (1987) 2773.
[61] K.R. Nielsen, J.P. Foley, J. Microcol. Sep. 5 (1993) 347.
[62] S. Wakida, S. Takeda, M. Yamane, A. Kawahara, K. Higashi, Anal. Sci. 7 (1991) 1109.

[63] W. Thormann, P. Meier, C. Marcolli, F. Binder, J. Chromatogr. 545 (1991) 445.
[64] P. Meier, W. Thormann, J. Chromatogr. 559 (1991) 505.
[65] A. Wainright, J. Microcol. Sep. 2 (1990) 166.
[66] A.S. Cohen, S. Terabe, J.A. Smith, B.L. Karger, Anal. Chem. 59 (1987) 1021.
[67] A.S. Cohen, A. Paulus, B.L. Karger, Chromatographia 24 (1987) 15.
[68] K. Saitoh, C. Kiyohara, N. Suzuki, J. High Resolut. Chromatogr. 14 (1991) 245.
[69] J. Vindevogel, R. Szucs, P. Sandra, L.C. Verhagen, J. High Resolut. Chromatogr. 14 (1991) 584.
[70] E. Van Hove, R. Szucs, P. Sandra, J. High Resolut. Chromatogr. 19 (1996) 674.
[71] S.D. Harvey, R.M. Bean, H.R. Udseth, J. Microcol. Sep. 4 (1992) 191.
[72] M.F. Renou-Gonnord, K. David, J. Chromatogr. A. 735 (1996) 249.
[73] M. Schafroth, W. Thormann, D. Allemann, Electrophoresis 15 (1994) 72.
[74] M.W.F. Nielen, M.J.A. Mensink, J. High Resolut. Chromatogr. 14 (1991) 417.
[75] H. Wolfisberg, A. Schmutz, R. Stotzer, W. Thormann, J. Chromatogr. A 652 (1993) 407.
[76] R. Guo, W. Thormann, Electrophoresis 14 (1993) 547.
[77] H.J. Gaus, A. Treumann, W. Kreis, E. Bayer, J. Chromatogr. 635 (1993) 319.
[78] A.E. Bretnall, G.S. Clarke, J. Chromatogr. A 700 (1995) 173.
[79] R.A. Wallingford, P.D. Curry Jr., A.G. Ewing, J. Microcol. Sep. 1 (1989) 23.
[80] R.A. Wallingford, A.G. Ewing, J. Chromatogr. 441 (1988) 299.
[81] R.A. Wallingford, A.G. Ewing, Anal. Chem. 61 (1989) 98.
[82] R.A. Wallingford, A.G. Ewing, Anal. Chem. 60 (1988) 258.
[83] C.P. Ong, S.F. Pang, S.P. Low, H.K. Lee, S.F.Y. Li, J. Chromatogr. 559 (1991) 529.
[84] T. Ueda, R. Mitchell, F. Kitamura, T. Metcalf, T. Kuwana, A. Nakamoto, J. Chromatogr. 593 (1992) 265.
[85] J. Liu, Y.Z. Hsieh, D. Wiesler, M. Novotny, Anal. Chem. 63 (1991) 408.
[86] C.J. Sciacchitano, B. Mopper, J.J. Specchio, J. Chromatogr. B 657 (1994) 395.
[87] T. Nakagawa, Y. Oda, A. Shibukawa, H. Tanaka, Chem. Pharm. Bull. 36 (1988) 1622.
[88] T. Nakagawa, Y. Oda, A. Shibukawa, H. Fukuda, H. Tanaka, Chem. Pharm. Bull. 37 (1989) 707.
[89] H. Nishi, T. Fukuyama, S. Terabe, J. Chromatogr. 553 (1991) 503.
[90] S. Terabe, Y. Miyashita, O. Shibata, E.R. Barnhart, L.R. Alexander, D.G. Patterson, B.L. Karger, K. Hosoya, N. Tanaka, J. Chromatogr. 516 (1990) 23.
[91] K. Otsuka, S. Terabe, T. Ando, J. Chromatogr. 396 (1987) 350.
[92] J. Prunonosa, R. Obach, A. Diez-Cascon, L. Gouesclou, J. Chromatogr. 574 (1992) 127.
[93] M. Korman, J. Vindevogel, P. Sandra, J. Chromatogr. 645 (1993) 366.
[94] H. Nishi, T. Fukuyama, M. Matsuo, S. Terabe, J. Pharm. Sci. 79 (1990) 519.
[95] S. Terabe, Y. Ishihama, H. Nishi, T. Fukuyama, K. Otsuka, J. Chromatogr. 545 (1991) 359.
[96] H. Nishi, M. Matsuo, J. Liq. Chromatogr. 14 (1991) 973.
[97] M. Miyake, A. Shibukawa, T. Nakagawa, J. High Resolut. Chromatogr. 14 (1991) 181.
[98] N. Bouaïcha, C. Rivassea, M.-C. Hennion, P. Sandra, J. Chromatogr. B 685 (1996) 53.
[99] M. Yu, N.J. Dovichi, Mikrochim. Acta 3 (1988) 27.
[100] M. Yu, N.J. Dovichi, Anal. Chem. 61 (1989) 37.
[101] K.C. Waldron, S. Wu, C.W. Earle, H.R. Harke, N.J. Dovichi, Electrophoresis 11 (1990) 777.
[102] H. Nishi, T. Fukuyama, M. Matsuo, S. Terabe, J. Chromatogr. 513 (1990) 279.
[103] Y. Miyashita and S. Terabe, Applications Data DS-767, Beckman Instruments, Fullerton, CA, 1990.
[104] C.P. Ong, C.L. Ng, H.K. Lee, S.F.Y. Li, J. Chromatogr. 559 (1991) 537.
[105] E. Skocir, J. Vindevogel, P. Sandra, Chromatographia 39 (1994) 7.
[106] S. Michaelsen, P. Moller, H. Sorensen, J. Chromatogr. A 680 (1994) 299.
[107] S. Terabe, Y. Miyashita, Y. Ishihama, O. Shibata, J. Chromatogr. 636 (1993) 47.
[108] M.-L. Riekkola, J.H. Jumppanen, J. Chromatogr. A 735 (1996) 151.
[109] D.F. Swaile, D.E. Burton, A.T. Balchunas, M.J. Sepaniak, J. Chromatogr. Sci. 26 (1988) 406.
[110] P. Wernly, W. Thormann, Anal. Chem. 64 (1992) 2155.
[111] P. Wernly, W. Thormann, Anal. Chem. 63 (1991) 2878.
[112] P. Davis, R. Lafon, T. Large, E.D. Morgan, I.D. Wilson, Chromatographia 37 (1993) 37.
[113] H.J. Issaq, K.C. Chan, G.M. Muschik, G.M. Janini, J. Liq. Chromatogr. 18 (1995) 1273.
[114] W. Kleiboehmer, K. Cammann, J. Robert, E. Mussenbrock, J. Chromatogr. 638 (1993) 349.
[115] D.M. Northrop, W.A. MacCrehan, J. Liq. Chromatogr. 15 (1992) 1041.
[116] D.M. Northrop, D.E. Martire, W.A. MacCrehan, Anal. Chem. 63 (1991) 1038.
[117] E. Mussenbrock, W. Kleibohmer, J. Microcol. Sep. 7 (1995) 107.
[118] M. Albin, R. Weinberger, E. Sapp, S. Moring, Anal. Chem. 63 (1991) 417.
[119] S.P.D. Lalljie, P. Sandra, Chromatographia 40 (1995) 519.
[120] P.G. Pietta, P.L. Mauri, A. Rava, G. Sabbatini, J. Chromatogr. 549 (1991) 367.
[121] Y.M. Liu, S.J. Sheu, Anal. Chim. Acta 288 (1994) 221.
[122] P. Pietta, C. Gardana, P. Mauri, J. High Resolut. Chromatogr. 15 (1992) 136.
[123] P. Pietta, A. Bruno, P. Mauri, A. Rava, J. Chromatogr. 593 (1992) 165.
[124] P. Pietta, P. Mauri, A. Bruno, L. Zini, J. Chromatogr. 638 (1993) 357.
[125] C. Delgado, F.A. Tomas-Barberan, T. Talou, A. Gaset, Chromatographia 38 (1994) 71.

[126] K.C. Chan, G.M. Janini, G.M. Muschik, H.J. Issaq, J. Chromatogr. A 653 (1993) 93.
[127] F. Tagliaro, F.P. Smith, S. Turrina, V. Equisetto, M. Marigo, J. Chromatogr. A. 735 (1996) 227.
[128] H. Nishi, T. Fukuyama, M. Matsuo, J. Microcol. Sep. 2 (1990) 234.
[129] S. Iwagami, Y. Sawabe, T. Nakagawa, Shoyakugaku Zasshi 45 (1991) 232.
[130] C. Kiyohara, K. Saitoh, N. Suzuki, J. Chromatogr. 646 (1993) 397.
[131] I.S. Lurie, K.C. Chan, T.K. Spratley, J.F. Casale, H.J. Issaq, J. Chromatogr. B 669 (1995) 3.
[132] J. Vindevogel, P. Sandra, J. High Resolut. Chromatogr. 14 (1991) 795.
[133] J. Vindevogel, P. Sandra, L.C. Verhagen, J. High Resolut. Chromatogr. 13 (1990) 295.
[134] R. Weinberger, I.S. Lurie, Anal. Chem. 63 (1991) 823.
[135] R. Szucs, J. Vindevogel, P. Sandra, L.C. Verhagen, Chromatographia 36 (1993) 323.
[136] L. Song, S. Zhang, Q. Qu, W. Yu, J. Microcol. Sep. 7 (1995) 123.
[137] A.D. Tran, T. Blanc, E.J. Leopold, J. Chromatogr. 516 (1990) 241.
[138] C. Desiderio, S. Fanali, A. Kuepfer, W. Thormann, Electrophoresis 15 (1994) 87.
[139] K. Saitoh, C. Kiyohara, N. Suzuki, Anal. Sci. 7 (1991) 269.
[140] S. Molteni, J. Caslavska, D. Alleman, W. Thormann, J. Chromatogr. B 658 (1994) 355.
[141] I.Z. Atamna, G.M. Janini, G.M. Muschik, H.J. Issaq, J. Liq. Chromatogr. 14 (1991) 427.
[142] T. Hyötyläinen, H. Sirén, M.-L. Riekkola, J. Chromatogr. A 735 (1996) 439.
[143] P. Wernly, W. Thormann, D. Bourquin, R. Brenneisen, J. Chromatogr. B 616 (1993) 305.
[144] T. Yashima, A. Tsuchiya, O. Morita, S. Terabe, Anal. Chem. 64 (1992) 2981.
[145] R.D. Holland, M.J. Sepaniak, Anal. Chem. 65 (1993) 1140.
[146] Y.F. Yik, H.K. Lee, S.F.Y. Li, J. High Resolut. Chromatogr. 15 (1992) 198.
[147] R. Weinberger, M. Albin, J. Liq. Chromatogr. 14 (1991) 953.
[148] M.G. Donato, W. Bayens, W. Van der Bossche, P. Sandra, J. Pharm. Biomed. Anal. 12 (1994) 21.
[149] A.F. Lecoq, C. Leuratti, E. Marafante, S. Di Biase, J. High Resolut. Chromatogr. 14 (1991) 667.
[150] T. Kaneta, S. Tanaka, M. Taga, H. Yoshida, J. Chromatogr. 609 (1992) 369.
[151] A. Lahey, R.L. St. Claire, III, Am. Lab. 22 (1990) 68.
[152] J.I. Ohms, Biotechnology Application Data DS-738, Beckman Instruments, Fullerton, CA, 1990.
[153] C.D. Bevan, I.M. Mutton, A.J. Pipe, J. Chromatogr. 636 (1993) 113.
[154] J. Liu, K.A. Cobb, M. Novotny, J. Chromatogr. 468 (1989) 55.
[155] R.G. Brownlee, S.W. Compton, Am. Lab. 20 (1988) 66.
[156] L. Kang, R.H. Buck, Amino Acids 2 (1992) 103.
[157] Y.F. Yik, C.P. Ong, S.B. Khoo, H.K. Lee, S.F.Y. Li, J. Chromatogr. 589 (1992) 333.
[158] T. Imasaka, K. Nishitani, N. Ishibashi, Anal. Chim. Acta 256 (1992) 3.
[159] T. Saitoh, H. Hoshino, T. Yotsuyanagi, J. Chromatogr. 469 (1989) 175.
[160] J. Caslavska, S. Lienhard, W. Thormann, J. Chromatogr. 638 (1993) 335.
[161] D. Perrett, G. Ross, Trends Anal. Chem. 11 (1992) 156.
[162] H. Nishi, N. Tsumagari, T. Kakimoto, S. Terabe, J. Chromatogr. 477 (1989) 259.
[163] H. Nishi, S. Terabe, Electrophoresis 11 (1990) 691.
[164] M.E. Swartz, J. Liq. Chromatogr. 14 (1991) 923.
[165] C.P. Ong, H.K. Lee, S.F.Y. Li, J. Chromatogr. 542 (1991) 473.
[166] S. Takeda, S. Wakida, M. Yamane, A. Kawahara, K. Higashi, Anal. Chem. 65 (1993) 2489.
[167] L.G. Song, S.M. Zhang, Q.Y. Ou, W.L. Yu, Chromatographia 39 (1994) 682.
[168] M.L. Marina, I. Benito, J.C. Díez-Masa, M.J. González, J. Chromatogr. A 752 (1996) 265.
[169] V. Dolnik, J. Liu, F. Banks Jr., M.V. Novotny, P. Bocek, J. Chromatogr. 480 (1989) 321.
[170] T. Saitoh, H. Hoshino, T. Yotsuyanagi, Anal. Sci. 7 (1991) 495.
[171] K. Otsuka, S. Terabe, T. Ando, J. Chromatogr. 332 (1985) 219.
[172] M. Castagnola, D.V. Rossetti, L. Cassiano, R. Rabino, G. Nocca, B. Giardina, J. Chromatogr. 638 (1993) 327.
[173] C.P. Ong, C.L. Ng, H.K. Lee, S.F.Y. Li, Electrophoresis 15 (1994) 1273.
[174] W. Thormann, A. Minger, S. Molteni, J. Caslavska, P. Gebauer, J. Chromatogr. 593 (1992) 275.
[175] K.C. Chan, K.C. Lewis, J.M. Phang, H.J. Issaq, J. High Resolut. Chromatogr. 16 (1993) 560.
[176] D.E. Burton, M.J. Sepaniak, M.P. Maskarinec, Chromatographia 21 (1986) 583.
[177] P. Wernly, W. Thormann, J. Chromatogr. 608 (1992) 251.
[178] Z.Y. Zhang, M.J. Fasco, L.S. Kaminsky, J. Chromatogr. B 665 (1995) 201.
[179] C. Desiderio, S. Fanali, Electrophoresis 13 (1992) 698.
[180] J.Y. Zhao, D.Y. Chen, N.J. Dovichi, J. Chromatogr. 608 (1992) 117.
[181] R. Weinberger, E. Sapp, S. Moring, J. Chromatogr. 516 (1990) 271.
[182] Y.F. Yik, H.K. Lee, S.F.Y. Li, S.B. Khoo, J. Chromatogr. 585 (1991) 139.
[183] C.P. Ong, C.L. Ng, H.K. Lee, S.F.Y. Li, J. Chromatogr. 547 (1991) 419.
[184] S. Kobayashi, T. Ueda, M. Kikumoto, J. Chromatogr. 480 (1989) 179.
[185] S. Fujiwara, S. Iwase, S. Honda, J. Chromatogr. 447 (1988) 133.
[186] H. Nishi, N. Tsumagari, T. Kakimoto, S. Terabe, J. Chromatogr. 465 (1989) 331.
[187] G.M. McLaughlin, J.A. Nolan, J.L. Lindahl, R.H. Palmieri, K.W. Anderson, S.C. Morris, J.A. Morrison, T.J. Bronzert, J. Liq. Chromatogr. 15 (1992) 961.
[188] S. Boonkerd, M.R. Detaevernier, Y. Michotte, J. Chromatogr. A 670 (1994) 209.

[189] M. Tanaka, T. Ishida, T. Araki, A. Masuyama, Y. Nakatsuji, M. Okahara, S. Terabe, J. Chromatogr. 648 (1993) 469.
[190] K.J. Lee, J.J. Lee, D.C. Moon, Electrophoresis 15 (1994) 98.
[191] K.J. Lee, J.J. Lee, D.C. Moon, J. Chromatogr. 616 (1993) 135.
[192] M.T. Ackermans, F.M. Everaerts, J.L. Beckers, J. Chromatogr. 606 (1992) 229.
[193] V.C. Trenerry, J. Robertson, R.J. Wells, J. Chromatogr. A 708 (1995) 169.
[194] J. Liu, K.A. Cobb, M. Novotny, J. Chromatogr. 519 (1990) 189.
[195] P. Lukkari, H. Siren, M. Pantsar, M.L. Riekkola, J. Chromatogr. 632 (1993) 143.
[196] P. Lukkari, H. Vuorela, M.L. Riekkola, J. Chromatogr. A 652 (1993) 451.
[197] P. Lukkari, T. Nyman, M.L. Riekkola, J. Chromatogr. A 674 (1994) 241.
[198] H. Soini, T. Tsuda, M.V. Novotny, J. Chromatogr. 559 (1991) 547.
[199] V.C. Trenery, J. Robertson, R.J. Wells, Electrophoresis 15 (1994) 103.
[200] C. Bjergegaard, S. Michaelsen, K. Mortensen, H. Sorensen, J. Chromatogr. A 652 (1993) 477.
[201] S. Michaelsen, P. Moeller, H. Soerensen, J. Chromatogr. 608 (1992) 363.
[202] P.H. Corran, N. Sutcliffe, J. Chromatogr. 636 (1993) 87.
[203] T. Kaneta, S. Tanaka, M. Taga, H. Yoshida, Anal. Chem. 64 (1992) 798.
[204] P.G. Muijselaar, H.A. Claessens, C.A. Cramers, J. Chromatogr. A 735 (1996) 395.
[205] C. Bjergegaard, S. Michaelsen, H. Soerensen, J. Chromatogr. 608 (1992) 403.
[206] K. Otsuka, S. Terabe, T. Ando, J. Chromatogr. 332 (1985) 219.
[207] D. Crosby, Z. El Rassi, J. Liq. Chromatogr. 16 (1993) 2161.
[208] C.L. Ng, H.K. Lee, S.F.Y. Li, J. Chromatogr. Sci. 30 (1992) 167.
[209] N. Matsubara, S. Terabe, J. Chromatogr. A 680 (1994) 311.
[210] S. Crobels, W. Bayens, C. Dewaele, C. VanPetegham, J. Chromatogr. A 673 (1994) 267.
[211] J.T. Smith, Z. El Rassi, J. Chromatogr. A 685 (1994) 131.
[212] R.F.D. Jones, P. Camilleri, A.J. Kirby, G.N. Okafo, J. Chem. Soc., Chem. Commun. 11 (1994) 1311.
[213] S.A. Swedberg, J. Chromatogr. 503 (1990) 449.
[214] J.T. Smith, Z. El Rassi, J. Microcol. Sep. 6 (1994) 127.
[215] Y. Mechref, Z. El Rassi, Chirality 8 (1996) 518.
[216] C. Bjergegaard, L. Ingvardsen, H. Sorensen, J. Chromatogr. A 653 (1993) 99.
[217] D.D. Dalton, D.R. Taylor, D.G. Waters, J. Chromatogr. A 712 (1995) 365.
[218] S. Iwagami, Y. Sawabe, T. Nakagawa, Shoyakugaku Zasshi 46 (1992) 339.
[219] S.J. Sheu, C.F. Lu, J. High Resolut. Chromatogr. 18 (1995) 269.
[220] A.J. Ji, M.F. Nunez, D. Machacek, J.E. Ferguson, M.F. Iossi, P.C. Kao, J.P. Landers, J. Chromatogr. B 669 (1995) 15.
[221] R.O. Cole, M.J. Sepaniak, W.L. Hinze, J. Gorse, K. Oldiges, J. Chromatogr. 557 (1991) 113.
[222] R.O. Cole, M.J. Sepaniak, LC·GC 10 (1992) 380.
[223] R.O. Cole, R.D. Holland, M.J. Sepaniak, Talanta 39 (1992) 1139.
[224] R.O. Cole, M.J. Sepaniak, W.L. Hinze, J. High Resolut. Chromatogr. 13 (1990) 579.
[225] S. Iwagami, Y. Sawabe, T. Nakagawa, Shoyakugaku Zasshi 47 (1993) 222.
[226] G.N. Okafo, P. Camilleri, J. Microcol. Sep. 5 (1993) 149.
[227] H. Nishi, T. Fukuyama, M. Matsuo, J. Microcol. Sep. 1 (1989) 234.
[228] S. Terabe, M. Shibata, Y. Miyashita, J. Chromatogr. 480 (1989) 403.
[229] G.N. Okafo, C. Bintz, S.E. Clarke, P. Camilleri, J. Chem. Soc., Chem. Commun. 17 (1992) 1189.
[230] H. Nishi, T. Fukuyama, M. Matsuo, S. Terabe, J. Chromatogr. 515 (1990) 233.
[231] A. Aumatell, R.J. Wells, J. Chromatogr. A 688 (1994) 329.
[232] S. Takeda, S. Wakida, M. Yamane, A. Kawahara, K. Higashi, Anal. Sci. 7 (1991) 1113.
[233] H. Nishi, T. Fukuyama, M. Matsuo, S. Terabe, Anal. Chim. Acta 236 (1990) 281.
[234] G. Okafo, L. Burrow, S.A. Carr, G.D. Roberts, W. Johnson, P. Camilleri, Anal. Chem. 68 (1996) 4424.
[235] A. Dobashi, T. Ono, S. Hara, J. Yamaguchi, J. Chromatogr. 480 (1989) 413.
[236] K. Otsuka, S. Terabe, Electrophoresis 11 (1990) 982.
[237] J.R. Mazzeo, M.E. Swartz, E.R. Grover, Anal. Chem. 67 (1995) 2966.
[238] J.R. Mazzeo, E.R. Grover, M.E. Swartz, J.S. Petersen, J. Chromatogr. A 680 (1994) 125.
[239] M.E. Swartz, J.R. Mazzeo, E.R. Grover, P.R. Brown, J. Chromatogr. A 735 (1996) 303.
[240] H. Ozaki, S. Terabe, A. Ichihara, J. Chromatogr. A 680 (1994) 117.
[241] S. Yang, J.G. Bumgarner, M.G. Khaledi, J. High Resolut. Chromatogr. 18 (1995) 443.
[242] C.P. Palmer, M.Y. Khaled, H.M. McNair, J. High Resolut. Chromatogr. 15 (1992) 756.
[243] C.P. Palmer, H.M. McNair, J. Microcol. Sep. 4 (1993) 509.
[244] J. Wang, I.M. Warner, Anal. Chem. 66 (1994) 3773.
[245] C.P. Palmer, S. Terabe, Kuromatogurafi 16 (1995) 98.
[246] S.A. Kuzdzal, C.A. Monnig, G.R. Newkome, C.N. Moorefield, J. Chem. Soc., Chem. Commun. 18 (1994) 2139.
[247] P.G. Muijselaar, H.A. Claessens, C.A. Cramers, J.F.G.A. Jansen, E.W. Meijer, E.M.M. De Brabander-van den Berg, S. van der Wal, J. High Resolut. Chromatogr. 18 (1995) 121.
[248] M. Castagnola, L. Cassiano, A. Lupi, I. Messana, M. Patamia, R. Rabino, D.V. Rossetti, B. Giardina, J. Chromatogr. A 694 (1995) 463.
[249] N. Tanaka, T. Tanigawa, K. Hosoya, K. Kimata, T. Araki, S. Terabe, Chem. Lett. 6 (1992) 959.
[250] N. Tanaka, T. Fukutome, T. Tanigawa, K. Hosoya, K. Kimata, T. Araki, K.K. Unger, J. Chromatogr. A 699 (1995) 331.

[251] K. Baechmann, A. Bazzanella, I. Haag, K.Y. Han, R. Arnecke, V. Boehmer, W. Vogt, Anal. Chem. 67 (1995) 1722.
[252] N. Sutcliffe, P.H. Corran, J. Chromatogr. 636 (1993) 95.
[253] H.K. Kristensen, S.H. Hansen, J. Chromatogr. 628 (1993) 309.
[254] Y. Ishihama, Y. Oda, N. Asakawa, Anal. Chem. 68 (1996) 1028.
[255] X. Fu, J. Lu, A. Zhu, J. Chromatogr. A 735 (1996) 353.
[256] Y. Ishihama, Y. Oda, K. Uchikawa, N. Asakawa, Anal. Chem. 67 (1995) 1588.
[257] S.J. Gluck, M.H. Benkoe, R.K. Hallberg, K.P. Steele, J. Chromatogr. A 744 (1996) 141.
[258] S. Terabe, N. Matsubara, Y. Ishihama, Y. Okada, J. Chromatogr. 608 (1992) 23.
[259] Y. Ishihama, Y. Oda, A. Asakawa, Anal. Chem. 68 (1996) 4281.
[260] J.H. Aiken, C.W. Huie, Chromatographia 35 (1993) 448.
[261] R. Szucs, E. Van Hove, P. Sandra, J. High Resolut. Chromatogr. 19 (1996) 189.
[262] H. Watarai, Chem. Lett. (1991) 391
[263] L. Song, Q. Ou, W. Yu, G. Li, J. Chromatogr. A 699 (1995) 371.
[264] L. Vomastova, I. Miksik, Z. Deyl, J. Chromatogr. B 681 (1996) 107.
[265] R.L. Boso, M.S. Bellini, I. Miksik, Z. Dey, J. Chromatogr. A 709 (1995) 11.
[266] I. Bjørnsdottir, S.H. Hansen, J. Pharm. Biomed. Anal. 13 (1995) 687.
[267] W. Thormann, S. Lienhard, P. Wernly, J. Chromatogr. 636 (1993) 137.
[268] H.T. Rasmussen, L.K. Goebel, H.M. McNair, J. High Resolut. Chromatogr. 14 (1991) 25.
[269] H. Nishi, N. Tsumagari, S. Terabe, Anal. Chem. 61 (1989) 2434.
[270] Q. Wu, H.A. Claessens, C.A. Cramers, Chromatographia 33 (1992) 303.
[271] S. Iwagami, Y. Sawabe, T. Nakagawa, Shoyakugaku Zasshi 46 (1992) 49.
[272] S. Boonkerd, M. Lauwers, M.R. Detaevernier, Y. Michotte, J. Chromatogr. A 695 (1995) 97.
[273] C. Zhang, Z. Sun, D. Ling, J. Zheng, J. Guo, X. Li, J. Chromatogr. B 612 (1993) 287.
[274] M. Albin, R. Weinberger, E. Sapp, S. Moring, Anal. Chem. 63 (1991) 417.
[275] D.D. Dalton, D.R. Taylor, J. Microcol. Sep. 7 (1995) 513.
[276] N. Matsubara, K. Koezuka, S. Terabe, Electrophoresis 16 (1995) 580.
[277] Y. Tanaka, personal communication (Nippon Boehringer Ingelheim), 1997.
[278] D.A. Armstrong, Sep. Purif. Methods 14 (1985) 213.
[279] S. Terabe, T. Katsura, Y. Okada, Y. Ishihama, K. Otsuka, J. Microcol. Sep. 5 (1993) 23.
[280] E.S. Ahuja, J.P. Foley, Anal. Chem. 67 (1995) 2315.
[281] S. Katsuta, T. Tsumura, K. Saitoh, N. Teramae, J. Chromatogr. A 705 (1995) 319.
[282] S. Katsuta, K. Saitoh, Anal. Lett. 27 (1994) 743.
[283] S. Katsuta and K. Saitoh, J. Chromatogr. A, (1997) in press.
[284] N. Matsubara, S. Terabe, Chromatographia 34 (1992) 493.
[285] K. Koezuka, H. Ozaki, N. Matsubara, S. Terabe, J. Chromatogr. B 689 (1997) 3.
[286] T. Yamaguchi, K. Otsuka and S. Terabe, unpublished data (Himeji Institute of Technology, 1997).
[287] L. Yang and C.S. Lee, J. Chromatogr. A, (1997) in press.
[288] J.P. Quirino and S. Terabe, J. Chromatogr. A, (1997) in press.
[289] J.P. Quirino and S. Terabe, J. Chromatogr. A, submitted for publication.
[290] N. Tanaka, K. Nakagawa, H. Iwasaki, K. Hosoya, K. Kimata, T. Araki and D.G. Patterson, Jr., J. Chromatogr. A, (1997) in press.
[291] Y. Okada and S. Terabe, unpublished results (Himeji Institute of Technology), 1992.