

ON-LINE PRE-CONCENTRATION OF ARSENIC COMPOUNDS BY DYNAMIC  
pH JUNCTION-CAPILLARY ELECTROPHORESIS

ZILDAWARNI BINTI IRWAN

UNIVERSITI TEKNOLOGI MALAYSIA

ON-LINE PRE-CONCENTRATION OF ARSENIC COMPOUNDS BY DYNAMIC  
pH JUNCTION-CAPILLARY ELECTROPHORESIS

ZILDAWARNI BINTI IRWAN

A thesis submitted in fulfilment of the  
requirements for the award of the degree of  
Master of Science (Chemistry)

Faculty of Science  
Universiti Teknologi Malaysia

## ABSTRACT

Capillary electrophoresis (CE) with ultraviolet (UV) detection suffers from a poor concentration sensitivity resulting in a significant obstacle for analysis of part per billion levels of analytes in real samples. Therefore, there is a need to develop a simple yet effective pre-concentration method to enhance concentration sensitivity of trace level analytes in real samples for CE analysis. In this research, dynamic pH junction as an on-line pre-concentration method was employed for the determination of the animal feed additive roxarsone (3-nitro-4-hydroxyphenylarsonic acid) and four of its most possible degradation products (arsenite, arsenate, monomethylarsonic acid and dimethylarsinic acid). Phenylarsonic acid was included as an internal standard. The separation was conducted in a fused-silica capillary using 15 mM  $\text{Na}_2\text{HPO}_4\text{-Na}_3\text{PO}_4$  buffer, pH 10.6 and 15 mM  $\text{CH}_3\text{COOH}$ , pH 3.5 sample matrix at a voltage of 25 kV. Arsenite, arsenate, monomethylarsonic acid and dimethylarsinic acid were detected at 192 nm wavelength while phenylarsonic acid and roxarsone were detected at 254 nm wavelength. This on-line pre-concentration method, compared to the conventional capillary zone electrophoresis (CZE) method, resulted in an increased detection response of up to 51-fold in terms of peak height of arsenic compounds. The lower limit of detections (LODs) for the arsenic compounds obtained were in the range of 0.34-1.93  $\mu\text{g/L}$  in comparison with conventional capillary zone electrophoresis with the LODs in the range of 140-293  $\mu\text{g/L}$ . Reproducibility of the analytes in terms of migration time was in the range of 1.96-5.37% RSD. The proposed method was applied to the determination of roxarsone in chicken manure and soil samples. Roxarsone was extracted with distilled water and the analyte was then cleaned up using solid-phase extraction technique which uses a high anion exchange cartridge (HAX) as an off-line sample pre-concentration and sample clean up as well as  $\text{C}_{18}$  cartridge for further sample clean up mainly to remove organic contaminant before analysis using dynamic pH junction-CE. Recovery of the roxarsone obtained was  $70 \pm 1\%$  for chicken manure samples and  $72 \pm 2\%$  for soil samples.

## ABSTRAK

Elektroforesis rerambut (CE) dengan pengesan ultralembayung (UV) mempunyai kelemahan disebabkan kepekaan yang rendah terhadap kepekatan mengakibatkan halangan yang jelas bagi analisis pada tahap bahagian per billion kepekatan analit dalam sampel sebenar. Oleh itu, adalah perlu untuk membangun kaedah pra-pemekatan yang ringkas tetapi berkesan dalam meningkatkan kepekaan terhadap kepekatan analit yang rendah dalam sampel sebenar bagi analisis CE. Dalam penyelidikan ini, titian pH dinamik telah dipilih sebagai kaedah pra-pemekatan talian terus bagi penentuan makanan tambahan haiwan, roksarson (asid 3-nitro-4-hidroksifenilarsonik) dan empat hasil produk degradasi (arsenit, arsenat, asid monometilarsonik dan asid dimetilarsinik) yang paling mungkin. Asid fenilarsonik turut dimasukkan sebagai piawai dalaman. Pemisahan telah dijalankan di dalam turus rerambut silika menggunakan larutan penimbal 15 mM  $\text{Na}_2\text{HPO}_4\text{-Na}_3\text{PO}_4$ , pH 10.6 dan sampel matrik 15 mM  $\text{CH}_3\text{COOH}$ , pH 3.5 pada keupayaan 25 kV. Spesies arsenik tak organik dikesan pada 192 nm sementara spesies arsenik organik dikesan pada 254 nm. Kaedah pra-pemekatan talian terus ini menghasilkan peningkatan respons pengesanan sehingga 51-kali ganda terhadap ketinggian puncak sebatian arsenik berbanding kaedah elektroforesis zon rerambut konvensional (CZE). Had pengesanan yang rendah terhadap enam sebatian arsenik yang diperolehi berada dalam julat 0.34-1.93  $\mu\text{g/L}$  berbanding dengan had pengesanan elektroforesis zon rerambut konvensional yang berada dalam julat 140-293  $\mu\text{g/L}$ . Kebolehulangan analit terhadap masa dalam julat 1.96-5.37% RSD. Kaedah yang telah dicadangkan ini telah diaplikasikan bagi penentuan roksarson dalam sampel tahi ayam dan sampel tanah. Roksarson diekstrak menggunakan kaedah pengekstrakan larut air dan analit kemudiannya dibersihkan menggunakan teknik pengekstrakan fasa pepejal menggunakan kartrij penukaran anion tinggi (HAX) yang berfungsi untuk pra-pemekatan sampel secara talian tidak terus dan untuk membersihkan sampel dan kartrij  $\text{C}_{18}$  untuk membersihkan lagi sampel terutamanya dalam penyingkiran bahan pencemar organik sebelum dianalisis oleh titian pH dinamik-CE. Nilai perolehan semula bagi roksarson ialah  $70 \pm 1\%$  bagi sampel tahi ayam sementara  $72 \pm 2\%$  ialah nilai perolehan semula roksarson yang diperolehi bagi sampel tanah.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iii
	<b>ACKNOWLEDGEMENT</b>	iv
	<b>ABSTRACT</b>	v
	<b>ABSTRAK</b>	vi
	<b>TABLE OF CONTENTS</b>	vii
	<b>LIST OF TABLES</b>	xii
	<b>LIST OF FIGURES</b>	xiv
	<b>LIST OF SYMBOLS</b>	xvi
	<b>LIST OF ABBREVIATIONS</b>	xviii
	<b>LIST OF APPENDICES</b>	xx
<b>1</b>	<b>INTRODUCTION</b>	1
	Problem Statement and the Need of Study	1
	Objectives of Research	3
	Scope of Research	4
<b>2</b>	<b>LITERATURE REVIEW</b>	5
	2.1 Arsenic: Usage and Problems	5
	2.1.1 Roxarsone as an Animal Feed Supplement in Poultry Industry	6
	2.1.2 Environmental Entry of Roxarsone	7
	2.1.2.1 Degradation of Roxarsone in Poultry	7

	Litter to Soils and Natural Water	
2.2	Methods for the Determination of Roxarsone and Its Degradation Product	8
2.3	Capillary Electrophoresis	11
2.3.1	System Overview	11
2.3.2	Detection in Capillary Electrophoresis	12
2.3.3	Modes of Separation in Capillary Electrophoresis	13
2.4	Capillary Zone Electrophoresis	13
2.4.1	Electroosmotic Flow	14
2.4.2	Principle of Separation in Capillary Zone Electrophoresis	16
2.4.2.1	Electrophoretic Mobility	16
2.4.3	Separation Mechanism	17
2.4.4	Application of Capillary Electrophoresis for the Separation of Arsenic Compounds	19
2.5	On-Line Sample Pre-concentration	20
2.5.1	Stacking, Sweeping and Transient Isotachopheresis	22
2.5.2	Dynamic pH Junction	24
2.5.2.1	Separation Principle of Dynamic pH Junction	24
2.5.2.2	Mechanistic Model	25
2.5.2.3	Application of Dynamic pH Junction	26
<b>3</b>	<b>MATERIALS AND METHODS</b>	<b>29</b>
3.1	Chemicals	29
3.2	Instruments	29
3.3	Procedures	32
3.3.1	Preparation of Background Electrolyte (BGE) and Sample Matrix	32
3.3.2	Preparation of Sample Matrix	32
3.3.3	Preparation of Arsenic Standard Stock Solution	33

3.3.4	Preparation of Nitrosul Drinking Water Solution, Soil and Chicken Manure Sample	33
3.3.5	General Solid Phase Extraction (SPE) Procedure	35
3.3.6	General Electrophoresis and Dynamic pH Junction Procedures	35
3.3.7	Calibration Graph Procedure	36
3.3.8	Validation Procedure	37
<b>4</b>	<b>RESULTS AND DISCUSSIONS</b>	<b>38</b>
4.1	Separation of Arsenic Compounds Using Capillary Zone Electrophoresis	38
4.1.1	Effect of Background Electrolyte pH	38
4.1.2	Detection Wavelength	40
4.1.3	Applied Voltage	42
4.2	Quantitative Aspects of the Separation of Arsenic Species by Capillary Zone Electrophoresis	44
4.2.1	Calibration Lines, Correlation Coefficients and Limit of Detections	45
4.2.2	Reproducibility of Migration Times, Peak Height and Peak Area	46
4.2.3	Separation Efficiency	48
4.3	Dynamic pH Junction	49
4.3.1	Dynamic pH Junction Model of Arsenic Compounds	50
4.3.2	Dynamic pH junction method optimization	51
4.3.2.1	Effect of Sample Matrix pH	51
4.3.2.2	Effect of Sample Matrix Concentration	52
4.3.2.3	Effect of Type of Buffer	55
4.3.2.4	Effect of Background Electrolyte pH	57
4.3.2.5	Effect of Injection Length	57
4.3.2.6	Mass Balance	60
4.4	Quantitative Aspects of the Separation of Arsenic	61

	Species by Dynamic pH junction- Capillary Electrophoresis	
4.4.1	Calibration Lines, Correlation Coefficients and Limit of Detections	61
4.4.2	Sensitivity Enhancement Factors and Band Narrowing Factors	62
4.4.3	Reproducibility	63
4.4.4	Comparison on the Performance of the Dynamic pH junction and Capillary Zone Electrophoresis	64
4.5	Application of Dynamic pH Junction-Capillary Electrophoresis`	66
4.5.1	Solid phase Extraction Technique	67
4.5.1.1	Retention of As(V), MMA and roxarsone on C <sub>18</sub> and HAX cartridges	67
4.5.1.2	Elution of As(V), MMA and roxarsone from C <sub>18</sub> -HAX cartridge	68
4.5.1.2.1	Type of Eluting Solvent	68
4.5.1.2.2	Concentration of Eluting Solvent	69
4.5.1.2.3	Volume of Eluting Solvent	69
4.6	Quantitative Aspects of the Solid Phase Extraction- Dynamic pH junction Capillary Electrophoresis	70
4.6.1	Calibration lines, Correlation Coefficients and Limit of Detection	71
4.6.2	Reproducibility	72
4.7	Application of Solid Phase Extraction-Dynamic pH Junction-Capillary Electrophoresis	72
4.7.1	Drinking Water Sample	72
4.7.2	Soil Sample	73
4.7.3	Chicken Manure Sample	74

<b>5</b>	<b>CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDY</b>	79
5.1	Conclusions	79
5.2	Recommendations for Future Study	80
	<b>REFERENCES</b>	82
	Appendices A	93

## LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Possible environmental reaction mechanisms of roxarsone	8
3.1	Chemical name, abbreviation, structure and pKa values of the arsenic compounds used in this study	30
4.1	Migration times, $t$ and electrophoretic mobilities, $\mu_{ep}$ of arsenic compounds	41
4.2	Injected concentration of arsenic compounds in other CZE studies	45
4.3	Linear regression, $r^2$ and LODs of the arsenic compounds	47
4.4	Reproducibility of migration times and peak areas	48
4.5	Separation efficiency of arsenic compounds	48
4.6	Effect of the sample matrix pH on migration time and peak height of arsenic compounds	53
4.7	Comparison of peak areas without and with pre-concentration	61
4.8	Calibration lines, correlation coefficient ( $r^2$ ) and LODs for arsenic compounds in dynamic pH junction	62
4.9	Sensitivity Enhancement Factor ( $SEF_{height}$ ) and Band Narrowing Factor (BNFs) of arsenic compounds.	63
4.10	Reproducibility of migration time, corrected peak area and peak height of arsenic compounds.	64
4.11	Comparison of LODs, peak height and $SEF_{height}$	66

	between CZE without pre-concentration method and CZE with pre-concentration method (dynamic pH junction).	
4.12	Percentage of arsenic species eluted from HAX cartridge with several elution buffers	69
4.13	Percentage of arsenic species eluted from HAX cartridge using different concentration of acetic acid solution.	70
4.14	Percentage of arsenic species eluted from HAX cartridge using different volume of acetic acid solution	70
4.15	Calibration Lines, Correlation Coefficient ( $r^2$ ) and Limit of Detection (LODs)	71
4.16	Recovery of roxarsone in spiked soil and chicken manure samples	76

**LIST OF FIGURES**

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Instrumental set up of a capillary electrophoresis system	12
2.2	Representation of electroosmotic flow in a capillary.	15
2.3	Electroosmotic and laminar flow profiles	15
2.4	Separation by capillary zone electrophoresis with ‘normal’ electroosmotic flow and polarity.	18
2.5	Drawing of a capillary zone electropherogram indicating elution order.	18
2.6	Schematic diagrams of a dynamic pH junction model.	26
4.1	The effect of a 15 mM phosphate background electrolyte pH on the migration times of arsenic compounds	40
4.2	Effect of detection wavelength on the separation of six arsenic compounds	43
4.3	Effect of separation voltage on migration time of arsenic compounds	44
4.4	Electropherogram of separation of standard mixture of arsenic compounds using CZE	49
4.5	Effect of the sample matrix pH	54
4.6	Effect of sample matrix concentration on the detection bandwidths.	55
4.7	Effect of type of buffer on separation of arsenic compounds	56
4.8	The measured analyte electrophoretic mobility as a function of BGE pH	57

4.9	Electropherogram of the effect of the injection length	59
4.10	Effect of injection length on band narrowing	60
4.11	Electropherogram of separations of standard mixture of arsenic compounds without (a) and with (b) dynamic pH junction	65
4.12	Analysis of 4 ppm nitrosul drinking water solution using dynamic pH junction-CE.	73
4.13	SPE-dynamic pH junction analysis of soil extract spiked with 1.28 ppm roxarsone	75
4.14	SPE-dynamic pH junction analysis of chicken manure extract spiked with 1.28 ppm roxarsone	78

**LIST OF SYMBOLS**

cm	-	Centimeter
°C	-	Degree Celsius
g	-	Gram
g/mol	-	Gram per mol
kg	-	Kilogram
kg/L	-	Kilogram per Liter
kV	-	Kilo Volt
M	-	Molar
MΩ	-	Milli Ohm
mbar	-	Milli Bar
mA	-	Milli Ampere Unit
min	-	Minute
mL	-	Milli Liter
mM	-	Milli Molar
N	-	Separation efficiency
nL	-	Nano Liter
nm	-	Nano Meter
ppm	-	Parts per Million
ppb	-	Parts per Billion
$r^2$	-	Correlation coefficient
s	-	Second
t	-	Migration time
$\mu_{app}$	-	Electrophoretic mobility at the apparent charge of the analyte
$\mu_{EOF}$	-	Electroosmotic flow mobility

$\mu_{EP}$	-	Electrophoretic mobility
$\mu\text{m}$	-	Micro Meter
$\mu\text{L}$	-	Micro Liter
$v$	-	Electrophoretic velocity
$v_{EOF}$	-	Electroosmotic flow velocity

**LIST OF ABBREVIATIONS**

AAS	-	Atomic absorption spectrometry
AFS	-	Atomic fluorescence spectrometry
ASV	-	Anodic stripping voltammetry
As(III)	-	Arsenite
As(V)	-	Arsenate
BNFs	-	Band narrowing factors
BGE	-	Background electrolyte
CSV	-	Cathodic stripping voltammetry
CE	-	Capillary electrophoresis
CEC	-	Capillary electrochromatography
CGE	-	Capillary gel electrophoresis
CIEF	-	Capillary isoelectric focusing
CITP	-	Capillary isotachopheresis
CTAC	-	Cetyltrimethylammonium chloride
CZE	-	Capillary zone electrophoresis
DPASV	-	Differential pulse anodic stripping voltammetry
DPCSV	-	Differential pulse cathodic stripping voltammetry
DIBR	-	Detector to injection band width ratio
DMA	-	Dimethylarsinic acid
EOF	-	Electroosmotic flow
FASI	-	Field amplified sample injection
FSCE	-	Free solution capillary electrophoresis
HAX	-	High anion exchange
HG	-	Hydride generation

HG-AAS	-	Hydride generation atomic absorption spectrometry
HPLC	-	High performance liquid chromatography
ICP-AES	-	Inductively coupled plasma-atomic emission spectrometry
ICP-MS	-	Inductively coupled plasma-mass spectrometry
LV-FASI-CZE	-	Large volume field amplified stacking injection capillary zone electrophoresis
LODs	-	Limit of detections
MMA	-	Monomethylarsonic acid
MEKC	-	Micellar electrokinetic capillary chromatography
3-NHPAA	-	3-nitro-4-hydroxyphenylarsonic acid
PAA	-	Phenylarsonic acid
PDDAC	-	Poly(diallyldimethylammonium chloride)
RSD	-	Relative standard deviation
SEF <sub>height</sub>	-	Sensitivity enhancement factor in terms of peak height
SPE	-	Solid phase extraction
t-ITP	-	Transient isotachopheresis
UV	-	Ultra Violet
UV/VIS	-	Ultra Violet / Visible
V-DIF	-	Velocity-difference induced focusing

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
<b>A</b>	Publications from this study program	93

## CHAPTER 1

### INTRODUCTION

#### 1.1 Problem Statement and the Need of Study

3-nitro-4-hydroxyphenylarsonic acid (3-NHPAA or roxarsone) is an anthropogenic organoarsenic compound that is widely used as an additive in the poultry industry to control coccidial intestinal parasites, improve feed efficiency and enhance weight gain for better production of poultry. This food supplement does not accumulate in the tissue or feathers of chicken but is believed to be excreted unchanged in poultry litter. Normally, the waste from poultry litter is applied to nearby crop land as fertilizer to reduce the cost of transporting the litter. Once in the agricultural field, roxarsone degrades rapidly into a more mobile and toxic arsenic species and thus providing the sources for arsenic contamination of surface and groundwater (Garbarino *et al.*, 2001). Of the various sources of arsenic exposure to human health, drinking water that is derived from surface waters (rivers, lakes, reservoirs and ponds) and groundwater is the major source for human exposure to arsenic. Therefore, it is very important to study this organoarsenic compound and its transformation products for the determination and identification of these arsenic compounds in real environmental samples.

For the measurement of trace level of roxarsone and its degradation products, various methods have been developed such as hydride generation atomic absorption spectrometry, HG-AAS (Gonzalez *et al.*, 2003; Maiti *et al.*, 2004; Bortoleto *et al.*, 2005 and Anthemidis *et al.*, 2005), voltammetry (Greulach and Henze, 1995; Sun *et*

*al.*, 1997 and Kopanica and Novotny, 1998; Profumo *et al.*, 2005), high performance liquid chromatography, HPLC (Martin *et al.*, 1995; Stummeyer *et al.*, 1996 and Gomez *et al.*, 1997), inductively coupled plasma mass spectrometry, ICP-MS (Wangkarn and Pergantis, 1999; Jackson *et al.*, 2003; Niemela *et al.*, 2003; Yu *et al.*, 2003; Bednar *et al.*, 2004 and Zhang *et al.*, 2004). and capillary electrophoresis, CE (Lopez-Sanchez *et al.*, 1994; Van den Broeck and Vandecasteele, 1998; Greschonig *et al.*, 1998; Sun *et al.*, 2002 and Chen *et al.*, 2003).

In this research, CE has been chosen for the separation and determination of arsenic species because CE has the advantages of short analysis time, high separation efficiency, lower solvent consumption, small sample size and low operating costs compared to other techniques that have been favored such as HPLC and ICP-MS which are more expensive and more complex in their instrumentation.

Capillary electrophoresis (CE) is an evolution of traditional slab gel electrophoretic technique. All commercially available CE is usually equipped with UV/VIS detector due to its ease of operation. However, CE suffers from the poor concentration sensitivity when using UV detection because of the small injection volume and short optical path length (Simonet *et al.*, 2003). As a result, CE is often not suitable for the analysis of real environmental samples. Some efforts have been attempted to improve the detection sensitivity of CE including the use of Z-cells or bubble cells to extend the optical path length (Mainka and Bachmann, 1997), the use of highly sensitive detection methods such as laser-induced fluorescence (Chen *et al.*, 2003) sample enrichment via off-line solid phase extraction method (Rao *et al.*, 1999) and the use of on-line pre-concentration techniques (Zhang *et al.*, 2001 and Britz-McKibbin *et al.*, 2002). On-line pre-concentration technique is simple and do not require modification to the existing instrument, since electrophoretic focusing of analytes is effected within the same capillary used for separation and useful for sensitivity enhancement.

In general, on-line pre-concentration methods consist of four techniques; sample stacking, sweeping, transient isotachoporesis and dynamic pH junction (Lin and Kaneta, 2004). Among these techniques, dynamic pH junction was selected as an

on-line pre-concentration technique in this study because the focusing procedure of dynamic pH junction is easy to perform since it does not require coating of the capillary or the use of polarity switching, as it often necessary for large volume sample stacking (Zhang *et al.*, 2001). To our knowledge, there has been no report on focusing of arsenic compounds using on-line pre-concentration method based on the dynamic pH junction.

## 1.2 Objectives of Research

The optimum experimental conditions for simultaneous separation of arsenic compounds which consists of arsenite; As(III), arsenate; As(V), monomethylarsonic acid; MMA, dimethylarsinic acid; DMA, and 3-nitro-4-hydroxyphenylarsonic acid; roxarsone and phenylarsonic acid; PAA using CZE will be determined. Experimental parameters such as the type of buffer, pH of buffer solution, separation voltage and detection wavelengths were investigated.

An on-line pre-concentration technique using the dynamic pH junction-CE will be developed to increase the detection sensitivity of the arsenic compounds. The factors included in the optimization scheme are buffer pH, pH of the sample matrix, concentration of the sample matrix and injection lengths.

The percentage recoveries of spiked soil and chicken manure samples upon application of the dynamic pH junction method as an on-line pre-concentration method combined with the well developed solid phase extraction (SPE) method will be determined. SPE method is employed for the purpose of sample clean-up as well as an off-line sample pre-concentration. Two types of SPE cartridges were used, that is C<sub>18</sub> cartridge for sample clean up mainly to remove organic contaminant and HAX (high anion exchange) cartridge for the purpose of sample pre-concentration.

### 1.3 Scope of Research

Arsenic compounds i.e. arsenite; As(III), arsenate; As(V), monomethylarsonic acid; MMA, dimethylarsinic acid; DMA, 3-nitro-4-hydroxyphenylarsonic acid; roxarsone and phenylarsonic acid; PAA were determined using CE. These arsenic compounds were chosen because these compounds are the most probable degradation products of roxarsone while PAA serve as an internal standard. For the purpose of increasing the detection limit of these five arsenic compounds when using CE, the on-line pre-concentration method based on dynamic pH junction was used. Increasing the sensitivity is important for the analysis of trace level of arsenic compounds in environmental samples. The limit of detection (LOD) for these five arsenic compounds using dynamic pH junction and normal CZE mode were compared. The dynamic pH junction method was applied to spiked soil samples and spiked litter samples. In the case of spiked samples, the samples were passed through C<sub>18</sub> cartridge to remove the organic contaminant and the samples were further pre-concentrated using HAX (high anion exchange) cartridge prior to analysis by CE.

## REFERENCES

- Albert, M., Demesmay, C. and Rocca, J. L. (1995). Analysis of Organic and Non-Organic Arsenious or Selenious Compounds by Capillary Electrophoresis. *Fresenius J. Anal. Chem.* 351:426-432.
- Albert, M., Debusschere, L., Demesmay, C. and Rocca, J. L. (1997). Large-Volume Stacking for Quantitative Analysis of Anions in Capillary Electrophoresis I. Large Volume Stacking Without Polarity Switching. *J. Chromatogr. A.* 757:291–196.
- Albert, M., Debusschere, L., Demesmay, C. and Rocca, J. L. (1997a). Large-Volume Stacking for Quantitative Analysis of Anions in Capillary Electrophoresis I. Large Volume Stacking With Polarity Switching. *J. Chromatogr. A.* 757:281-289.
- Alpharma Inc (1999). *3-Nitro vs Arsanilic Acid*. NJ (USA): Technical Bulletin.
- Anthemidis, A. N., Zachariadis, G. A. and Stratis, J. A. (2005). Determination of Arsenic (III) and Total Inorganic Arsenic in Water Samples Using an On-line Sequential Insertion System and Hydride Generation Atomic Absorption Spectrometry. *Anal. Chim. Acta.* 547:237-242.
- Arai, Y., Lanzirotti, A., Sutton, S., Davis, J. A. and Sparks, D. L. (2003). Arsenic Speciation and Reactivity in Poultry Litter. *Environ. Sci. Technol.* 37:4083-4090.
- Bachmann, K., Gottlicher, B., Haag, I., Hannina, M. and Hensel, W. (1994). Sample Stacking for Charged Phenol Derivatives in Capillary Zone Electrophoresis. *Fresenius J. Anal. Chem.* 350:368-371.
- Baker, D. R. (1995). *Capillary Electrophoresis*. New York: John Wiley & Sons, Inc.
- Bednar, A. J., Garbarino, J. R., Burkhardt, M. R., Ranville, J. F. and Wildeman, T. R. (2004). Field and Laboratory Arsenic Speciation Methods and Their Application to Natural-Water Analysis. *Water Res.* 38:355-364.

- Bednar, A. J., Garbarino, J. R., Ferrer, I., Rutherford, D. W., Wershaw, R. L., Ranville, J. F. and Wildeman, T. R. (2002). Photodegradation of Roxarsone in Poultry Litter Leachates. *Sci. Total Environ.* 302:237-245.
- Bocek, P., Deml, M., Pospical, J. and Sudor, J. (1989). Dynamic Programming of pH- A New Option in Analytical Capillary Electrophoresis. *J. Chromatogr.* 470:309-312.
- Bortoleto, G. G. and Cadore, S. (2005). Determination of Total Inorganic Arsenic in Water Using On-line Pre-concentration and Hydride-Generation Atomic Absorption Spectrometry. *Talanta.* 67:169-174.
- Britz-McKibbin, P., Bebault, G. M. and Chen, D. D. Y. (2000). Velocity-Difference Induced Focusing of Nucleotides in Capillary Electrophoresis with a Dynamic pH Junction. *Anal.Chem.* 72:1729-1735.
- Britz-McKibbin, P. and Chen, D. D. Y. (2000). Selective Focusing of Catecholamines and Weakly Acidic Compounds by Capillary Electrophoresis Using a Dynamic pH Junction. *Anal. Chem.* 72:1242-1252.
- Britz-McKibbin, P., Otsuka, K. and Terabe, S. (2002). On-Line Focusing of Flavin Derivatives Using Dynamic pH Junction-Sweeping Capillary Electrophoresis with Laser-Induced Fluorescence Detection. *Anal.Chem.* 74:3736-3743.
- Britz-McKibbin, P. and Terabe, S. (2003). On-line Preconcentration Strategies for Trace Analysis of Metabolites by Capillary Electrophoresis: A Review. *J. Chromatogr. A.* 1000:917-934.
- Britz-McKibbin, P., Nishioka, T. and Terabe, S. (2003). Sensitive and High-Throughput Analyses of Purine Metabolites by Dynamic pH Junction Multiplexed Capillary Electrophoresis: A New Tool for Metabolomic Studies. *Analytical Sciences.* 19:99-104.
- Britz-McKibbin, P., Ichihashi, T., Tsubota, K., Chen, D. D. Y. and Terabe, S. (2003a). Complementary On-Line Preconcentration Strategies for Steroids by Capillary Electrophoresis. *J. Chromatogr. A.* 1013:65-76.
- Britz-McKibbin, P., Markuszewski, M. J., Iyanagi, T., Matsuda, K., Nishioka, T. and Terabe, S. (2003b). Picomolar Analysis of Flavins in Biological Samples by Dynamic pH Junction-Sweeping Capillary Electrophoresis with Laser-Induced Fluorescence Detection. *Anal. Biochem.* 313:89-96.

- Brown, B. L., Slaughter, A. D., and Schreiber, M. E. (2005). Controls on Roxarsone Transport in Agricultural Watersheds. *Applied Geochemistry*. 20:123-133.
- Chen, S. J., Chen, M. J. and Chang, H. T. (2003). Light-Emitting Diode-Based Indirect Fluorescence Detection for Simultaneous Determination of Anions and Cations in Capillary Electrophoresis. *J. Chromatogr. A*. 1017:215-224.
- Chen, Z. L., Lin, J. M. and Naidu, R. (2003a). Separation of Arsenic Species by Capillary Electrophoresis with Sample-Stacking Techniques. *Anal. Bioanal. Chem.* 375:679-684.
- Demesmay, C., Olle, M. and Pothault, M. (1994). Arsenic Speciation by Coupling High-Performance Liquid Chromatography with Inductively Coupled Plasma Mass Spectrometry. *Fresenius J. Anal. Chem.* 348:205-210.
- Do, B., Robinet, S., Pradeau, D. and Guyon, F. (2001). Speciation of Arsenic and Selenium Compounds by Ion-Pair Reversed-Phase Chromatography with Electrothermic Atomic Absorption Spectrometry: Application of Experimental Design for Chromatographic Optimisation. *J. Chromatogr. A*. 918:87-98.
- Dugo, G., Pera, L. L., Turco, V. L. and Bella, G. D. (2005). Speciation of Inorganic Arsenic in Alimentary and Environmental Aqueous Samples by Using Derivative Anodic Stripping Chronopotentiometry (dACSP). *Chemosphere*. 61:1093-1101.
- Fan, L., Liu, L., Chen, H., Chen, X. and Hu, Z. (2005). Continuous On-Line Concentration Based on Dynamic pH Junction for Trimethoprim and Sulfamethoxazole by Microfluidic Capillary Electrophoresis Combined with Flow Injection Analysis System. *J. Chromatogr. A*. 1062:133-137.
- Foret, F., Krivankova, L. and Bocek, P. (1993). *Capillary Zone Electrophoresis*. Weinheim: VCH Publishers, Inc. 56-57.
- Frerichs, V. A., Herrmann, J. K., Aguirre, A. and Colon, L. A. (2004). Trace Level Determination of Substance P by Using Capillary Electrophoresis and Laser-Induced Fluorescence. *Microchemical Journal*. 78:135-142.
- Garbarino, J. R., Rutherford, D. W. and Wershaw, R. L. (2001). Degradation of Roxarsone in Poultry Litter: In the Proceedings of Arsenic in the Environment Workshop. U.S. Geological Survey.

- Garbarino, J. R., Bednar, A. J., Rutherford, D. W., Beyer, R. S. and Wershaw, R. L. (2003). Environmental Fate of Roxarsone in Poultry Litter. I. Degradation of Roxarsone during Composting. *Environ. Sci. Technol.* 37:1509-1514.
- Gil, E. P., Ostapczuk, P. and Emons, H. (1999). Determination of Arsenic Species by Field Amplified Injection Capillary Electrophoresis after Modification of the Sample Solution with Methanol. *Anal. Chim. Acta.* 389:9–19.
- Gomez, M., Camara, C. Palacios, M. A. and Lopez-Gonzalvez, A. (1997). Anionic Cartridge Preconcentrators for Inorganic Arsenic, Monomethylarsonate and Dimethylarsinate Determination by On-line HPLC-HG-AAS. *Fresenius J. Anal. Chem.* 357:844-849.
- Gonzalez, J. C., Lavilla, I. and Bendicho, C. (2003). Evaluation of Non-Chromatographic Approaches for Speciation of Extractable As(III) and As(V) in Environmental Solid Samples by FI-HGAAS. *Talanta.* 59:525-534.
- Greschonig, H., Schmid, M. G. and Gubitzi, G. (1998). Capillary Electrophoretic Separation of Inorganic and Organic Arsenic Compounds. *Fresenius J. Anal. Chem.* 362:218–223.
- Greulach, U. and Henze, G. (1995). Analysis of Arsenic(V) by Cathodic Stripping Voltammetry. *Anal. Chim. Acta.* 306:217-223.
- Grossman, P. D. and Colburn, J. C. (1992). *Capillary Electrophoresis: Theory & Practice*. San Diego: Academic Press, Inc.
- Gupta, G. and Doherty, M. (1990). Effect of Composting and Number of Flocks on Poultry Litter Extract BOD and Toxicity. *Water, Air and Soil Pollution.* 51:139-145.
- Han, F. X., Kingery, W. L., Selim, H. M., Gerard, P. D., Cox, M. S. and Oldham, J. L. (2004). Arsenic Solubility and Distribution in Poultry Waste and Long-Term Amended Soil. *The Science of the Total Environment.* 320:51-61.
- Heathman, G. C., Sharpley, A. N., Smith, S. J. and Robinson, J. S. (1995). Land Application of Poultry Litter and Water Quality in Oklahoma, U.S.A. *Fertilizer Research.* 40:165-173.
- He, Y., Zheng, Y., Ramnaraine, M. and Locke, D. C. (2004). Differential Pulse Cathodic Stripping Voltammetric Speciation of Trace Level Inorganic Arsenic Compounds in Natural Water Samples. *Anal. Chim. Acta.* 511:55-61.

- Jackson, B. P., Bertsch, P. M., Cabrera, M. L., Camberato, J. J., Seaman, J. C. and Wood, C. W. (2003). Trace Element Speciation in Poultry Litter. *J. Environ. Qual.* 32:535-540.
- Jain, C. K. and Ali, I. (2000). Arsenic: Occurrence, Toxicity and Speciation Techniques. *Water. Res.* 34:4304-4312.
- Sathrugnan, K. and Hirata, S. (2004). Determination of Inorganic Oxyanions of As and Se by HPLC-ICPMS. *Talanta.* 64:237-243.
- Kim, J. B., Britz-McKibbin, P., Hirokawa, T. and Terabe, S. (2003). Mechanistic Study on Analyte Focusing by Dynamic pH Junction in Capillary Electrophoresis Using Computer Simulation. *Anal.Chem.* 75:3986-3993.
- Kim, J. B., Okamoto, Y. and Terabe, S. (2003a). On-Line Sample Preconcentration of Cationic Analytes by Dynamic pH Junction in Capillary Electrophoresis. *J. Chromatogr. A.* 1018:251-256.
- Kopanica, M. and Novotny, L. (1998). Determination of Traces of Arsenic(III) by Anodic Stripping Voltammetry in Solutions, Natural Waters and Biological Material. *Anal. Chim. Acta.* 368:211-218.
- Leermakers, M., Baeyens, W., de Gieter, M., Smedts, B., Meert, C., de Bisschop, H. C., Morabito, R. and Quevauviller. Ph. (2006). Toxic Arsenic Compounds in Environmental Samples: Speciation and Validation. *Trends Anal. Chem.* 25:1-9.
- Le, X. C. and Ma, M. (1997). Speciation of Arsenic Compounds by Using Ion-Pair Chromatography with Atomic Spectrometry and Mass Spectrometry Detection. *J. Chromatogr A.* 764:55-64.
- Le, X. C., Ma, M., Lu, X., Cullen, W. R., Aposhian, H. V. and Zheng, B. (2000). Determination of Monomethylarsonous Acid, a Key Arsenic Methylation Intermediate, in Human Urine. *Environmental Health Perspectives.* 108:1015-1018.
- Lin, C. H and Kaneta, T. (2004). On-Line Sample Concentration Techniques in Capillary Electrophoresis: Velocity Gradient Techniques and Sample Concentration Techniques for Biomolecules: A Review. *Electrophoresis.* 25:4058-4073.
- Lindemann, T., Prange, A., Dannecker, W. and Neidhart, B. (1999). Simultaneous Determination of Arsenic, Selenium and Antimony Species Using HPLC/ICP-MS. *Fresenius J. Anal. Chem.* 364:462-466.

- Lintschinger, J., Schramel, P., Hatalak-Rauscher, A., Wendler, I. and Michalke, B. (1998). A New Method for the Arsenic Species in Urine by Using HPLC-ICP-MS. *Fresenius J. Anal. Chem.* 362:313-318.
- Li, S. F. Y. (1992). *Capillary Electrophoresis: Principles, Practice and Application*. Amsterdam: Elsevier.
- Li, X., Jia, J. and Wang, Z. (2006). Speciation of Inorganic Arsenic by Electrochemical Hydride Generation Atomic Absorption Spectrometry. *Anal. Chim. Acta.* 560:153-158.
- Li, Z. I., Mou, S. F., Ni, Z. M and Riviello, J. M. (1995). Sequential Determination of Arsenite and Arsenate by Ion Chromatography. *Anal. Chim. Acta.* 307:79-87.
- Liu, X., Ma, L., Lin, Y. W. and Lu, Y. T. (2003). Determination of Abscisic Acid by Capillary Electrophoresis with Laser-Induced Fluorescence Detection. *J. Chromatogr. A.* 1021:209-213.
- Londesborough, S., Mattusch, J. and Wennrich, R. (1999). Separation of Organic and Inorganic Arsenic Species by HPLC-ICP-MS. *Fresenius J. Anal. Chem.* 363:577-581.
- Lopez-Sanchez, J. F., Amran, M. B., Lakkis, M. D., Lagarde, F., Rauret G. and Leroy, M. J. F. (1994). Quantitative Aspects of the Separation of Arsenical Species by Free Solution Capillary Electrophoresis. *Fresenius. J. Anal. Chem.* 348:810-814.
- Mainka, A. and Bachmann, K. (1997). UV Detection of Derivatized Carbonyl Compounds in Rain Samples in Capillary Electrophoresis Using Sample Stacking and a Z-Shaped Flow Cell. *J. Chromatogr. A.* 767:241-247.
- Maity, S., Chakravarty, S., Thakur, P., Gupta, K. K., Bhattacharjee, S. and Roy, B. C. (2004). Evaluation and Standardisation of a Simple HG-AAS Method for Rapid Speciation of As(III) and As(V) in Some Contaminated Groundwater Samples of West Bengal, India. *Chemosphere.* 54:1199-1206.
- Mandal, B. K. and Suzuki, K. T. (2002). Arsenic Round the World: A Review. *Talanta.* 58:201-235.
- Martin, I., Lopez-Gonzalvez, M. A., Gomez, M., Camara, C. and Palacios, M. A. (1995). Evaluation of High-Performance Liquid Chromatography for the Separation and Determination of Arsenic Species by On-line High Performance Liquid

- Chromatographic-Hydride Generation-Atomic Absorption Spectrometry. *J. Chromatogr. B.* 666:101-109.
- Mester, Z. and Fodor, P. (1996). High-Performance Liquid Chromatography-Hydride Generation-Atomic Fluorescence Spectroscopic Determination of Arsenic Species in Water. *J. Chromatogr. A.* 756:292-299.
- Monton, M. R. N., Imami, K., Nakanishi, M., Kim, J. B. and Terabe, S. (2005). Dynamic pH Junction Technique for On-Line Preconcentration of Peptides in Capillary Electrophoresis. *J. Chromatogr. A.* 1079:266-273.
- Moreda-Pineiro, J. Moscoso-Perez, C., Lopez-Mahia, P., Muniategui-Lorenzo, S., Fernandez-Fernandez, E. and Prada-Rodriguez, D. (2001). Multivariate Optimisation of Hydride Generation Procedures for Single Element Determinations of As, Cd, Sb and Se in Natural Waters by Electrothermal Atomic Absorption Spectrometry. *Talanta.* 53:871-883.
- Morin, P., Amran, M. B., Favier, S., Heimbürger, R., and Leroy, M. (1992). Separation of Arsenic Anions by Capillary Zone Electrophoresis with UV Detection. *Fresenius J. Anal. Chem.* 342:357-362.
- Morrison, J. L. (1969). Distribution of Arsenic from Poultry Litter in Broiler Chickens, Soil and Crop. *J. Agr. Food Chem.* 17:1288-1290.
- Narcise, C. I. S., Lilibeth dI.C.Coo, Florian R. del Mundo. (2005). On-line Preconcentration and Speciation of Arsenic by Flow Injection Hydride Generation Atomic Absorption Spectrophotometry. *Talanta.* 68:298-304.
- Nesbitt, C. A., Lo, J. T. M. and Yeung, K. K. -C. (2005). Over 1000-Fold Protein Preconcentration for Microliter-Volume Samples at a pH Junction Using Capillary Electrophoresis. *J. Chromatogr. A.* 1073:175-180.
- Niedzielski, P. (2005). The New Concept of Hyphenated Analytical System: Simultaneous Determination of Inorganic Arsenic(III), Arsenic(V), Selenium(IV) and Selenium(VI) by High Performance Liquid Chromatography-Hydride Generation-(*fast sequential*) Atomic Absorption Spectrometry During Single Analysis. *Anal. Chim. Acta.* 551:199-206.

- Niemala, M., Peramaki, P., Kola, H. and Piispanen, J. (2003). Determination of Arsenic, Iron and Selenium in Moss Samples Using Hexapole Collision Cell, Inductively Coupled Plasma-Mass Spectrometry. *Anal. Chim. Acta.* 493:3-12.
- Pergantis, S. A., Cullen, W. R., Chow, D. T. and Eigendor, K. (1997). Liquid Chromatography and Mass Spectrometry for the Speciation of Arsenic in Animal Feed Additives. *J. Chromatogr. A.* 764:211-222.
- Pittman, J. L., Gessner, H. J., Frederick, K. A., Raby, E. M., Batts, J. B. and Gilman, S. D. (2003). Experimental Studies of Electroosmotic Flow Dynamics during Sample Stacking for Capillary Electrophoresis. *Anal. Chem.* 75:3531-3538.
- Profumo, A., Merli, D. and Pesavento, M. (2005). Voltammetric Determination of Inorganic As(III) and Total Inorganic As in Natural Waters. *Anal. Chim. Acta.* 539:245-250.
- Qin, J., Fung, Y., Zhu, D. and Lin, B. (2004). Native Fluorescence Detection of Flavin Derivatives by Microchip Capillary Electrophoresis with Laser-Induced Fluorescence Intensified Charge-Coupled Device Detection. *J. Chromatogr. A.* 1027:223-229.
- Quirino, J. P. and Terabe, S. (1998). On-line Concentration of Neutral Analytes for Micellar Electrokinetic Chromatography IV. Field-Enhanced Sample Injection. *J. Chromatogr. A.* 798:251-257.
- Quirino, J. P. and Terabe, S. (2000). Approaching a Million-Fold Sensitivity Increase in Capillary Electrophoresis with Direct Ultraviolet Detection: Cation-Selective Exhaustive Injection and Sweeping. *Anal. Chem.* 72:1023-1030.
- Rao, L. V., Petersen, J. R., Bissell, M. G., Okorodudu, A. O. and Amin, A. M. (1999). Development of a Urinary Free Cortisol Assay Using Solid-Phase Extraction-Capillary Electrophoresis. *J. Chromatogr. B.* 730:123-128.
- Roerdink, A. R. and Aldstadt III, J. H. (2005). Sequential Injection Absorption Spectrophotometry Using a Liquid-Core Waveguide: Determination of  $p$ -Arsanilic Acid in Natural Waters. *Anal. Chim. Acta.* 539:181-187.
- Rosal, C. G., Momplaisir, G. M. and Heithmar, E. M. (2005). Roxarsone and Transformation Products in Chicken Manure: Determination by Capillary

- Electrophoresis- Inductively Coupled Plasma-Mass Spectrometry. *Electrophoresis*. 26:1606-1614.
- Sathrugnan, K. and Hirata, S. (2004). Determination of Inorganic Oxyanions of As and Se by HPLC-ICPMS. *Talanta*. 64:237-243.
- Segura, M., Munoz, J., Madrid, Y. and Camara, C. (2002). Stability Study of As(III), As(V), MMA and DMA by Anion Exchange Chromatography and HG-AFS in Wastewater Samples. *Anal. Bioanal. Chem.* 374:513-519.
- Sierra-Alvarez, R., Cortinas, I., Yenal, U. and Field, J. A. (2004). Methanogenic Inhibition by Arsenic Compounds. *Appl. Environ. Microbiol.* 70:5688-5691.
- Simonet, B. M., Rios, A. and Valcarcel, M. (2003). Enhancing Sensitivity in Capillary Electrophoresis. *Trends Anal. Chem.* 22:605-614.
- Stummeyer, J., Harazim, B. and Wipperman, T. (1996). Speciation of Arsenic in Water Samples by High-Performance Liquid Chromatography-Hydride Generation-Atomic Absorption Spectrometry at Trace Levels Using a Post-Column Reaction System. *Fresenius J. Anal. Chem.* 354:344-351.
- Sun, B., Haddad, P. R. and Macka, M. (2002). Separation of Organic and Inorganic Arsenic Species by Capillary Electrophoresis Using Direct Spectrometric Detection. *Electrophoresis*. 23:2430-2438.
- Sun, B., Haddad, P. R. and Macka, M. (2004). Speciation of Arsenic and Selenium by Capillary Electrophoresis. *J. Chromatogr. A*. 1039:201-208.
- Sun, Y. C., Mierzwa, J. and Yang, M. H. (1997). New Method of Gold-Film Electrode Preparation for Anodic Stripping Voltammetric Determination of Arsenic (III and V) in Seawater. *Talanta*. 44:1379-1387.
- USEPA, (2001). *Drinking Water Standards*. US. US Environmental Protection Agency.
- Van den Broeck, K. and Vandecasteele, C. (1998). Capillary Electrophoresis for the Speciation of Arsenic. *Mikrochim. Acta*. 128:79-85.
- Vanhaecke, F. and Moens, L. (1999). Recent Trends in Trace Element Determination and Speciation Using Inductively Coupled Plasma Mass Spectrometry. *Fresenius J. Anal. Chem.* 364:440-451.

- Wangkarn, S. and Pergantis, S. A. (1999). Determination of Arsenic in Organic Solvents and Wines Using Microscale Flow Injection Inductively Coupled Plasma Mass Spectrometry. *J. Anal. At. Spectrom.* 14:657-662.
- Wang, S. J., Tseng, W. L., Lin, Y. W. and Chang, H. T. (2002). On-Line Concentration of Trace Proteins by pH Junctions in Capillary Electrophoresis with UV Absorption Detection. *J. Chromatogr. A.* 979:261-270.
- Wershaw, R. L., Rutherford, D. W., Rostad, C. E., Garbarino, J. R., Ferrer, I., Kennedy, K. R., Momplaisir, G. M. and Grange, A. (2003). Mass Spectrometric Identification of an Azobenzene Derivative Produced by Smectite-catalyzed Conversion of 3-amino-4-hydroxyphenylarsonic Acid. *Talanta.* 59:1219-1226.
- Wershaw, R. L., Garbarino, J. R. and Burkhardt, M. R. (1999). Roxarsone in Natural Water Systems. In: Effects of Animal Feeding Operations on Water Resources and the Environment. Proceedings of Technical Meeting. U.S. Geological Survey, Fort Collins. USA.
- Yalcin, S. and Le, X. C. (1998). Low Pressure Chromatographic Separation of Inorganic Arsenic Species Using Solid Phase Extraction Cartridges. *Talanta.* 47:787-796.
- Yalcin, S. and Le, X. C. (2001). Speciation of Arsenic Using Solid Phase Extraction Cartridges. *J. Environ. Monit.* 3:81-85.
- Yang, C., Zhang, L., Liu, H., Zhang, W. and Zhang, Y. (2003). Two-Dimensional Capillary Electrophoresis Involving Capillary Isoelectric Focusing and Capillary Zone Electrophoresis. *J. Chromatogr. A.* 1018:97-103.
- Yin, X. B. (2004). On-line Preconcentration for Capillary Electrophoresis-Atomic Fluorescence Spectrometric Determination of Arsenic Compounds. *Electrophoresis.* 25:1837-1842.
- Yu, B., Cong, H., Liu, H., Li, Y. and Liu, F. (2005). Separation and Detection of Erythropoietin by CE and CE-MS. *Trends Anal. Chem.* 24:350-357.
- Yu, C., Cai, Q., Guo, Z. X., Yang, Z. and Khoo, S. B. (2003). Inductively Coupled Plasma Mass Spectrometry Study of the Retention Behavior of Arsenic Species on Various Solid Phase Extraction Cartridges and Its Application in Arsenic Speciation. *Spectrochimica Acta Part B.* 58:1335-1349.

- Yu, L. and Li, S. F. Y. (2005). Dynamic pH Junction-Sweeping Capillary Electrophoresis for Online Preconcentration of Toxic Pyrrolizidine Alkaloids in Chinese Herbal Medicine. *Electrophoresis*. 26:4360-4367.
- Zhang, P., Xu, G., Xiong, J., Yang, Q. and Wei, F. (2001). Determination of Arsenic Species by Capillary Zone Electrophoresis with Large-Volume Field-Amplified Stacking Injection. *Electrophoresis*. 22:3567-3572.
- Zhang, Z., Chen, S., Yu, H., Sun, M. and Liu, W. (2004). Simultaneous Determination of Arsenic, Selenium and Mercury by Ion Exchange-Vapor Generation-Inductively Coupled Plasma-Mass Spectrometry. *Anal. Chim. Acta*. 513:417-423.
- Zheng, J., Goessler, W. and Kosmus, W. (1998). Speciation of Arsenic Compounds by Coupling High-Performance Liquid Chromatography with Inductively Coupled Plasma Mass Spectrometry. *Mikrochim. Acta*. 130:71-79.