IC-MS Analysis of Haloacetic Acids

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Ion Chromatography Sample Preparation

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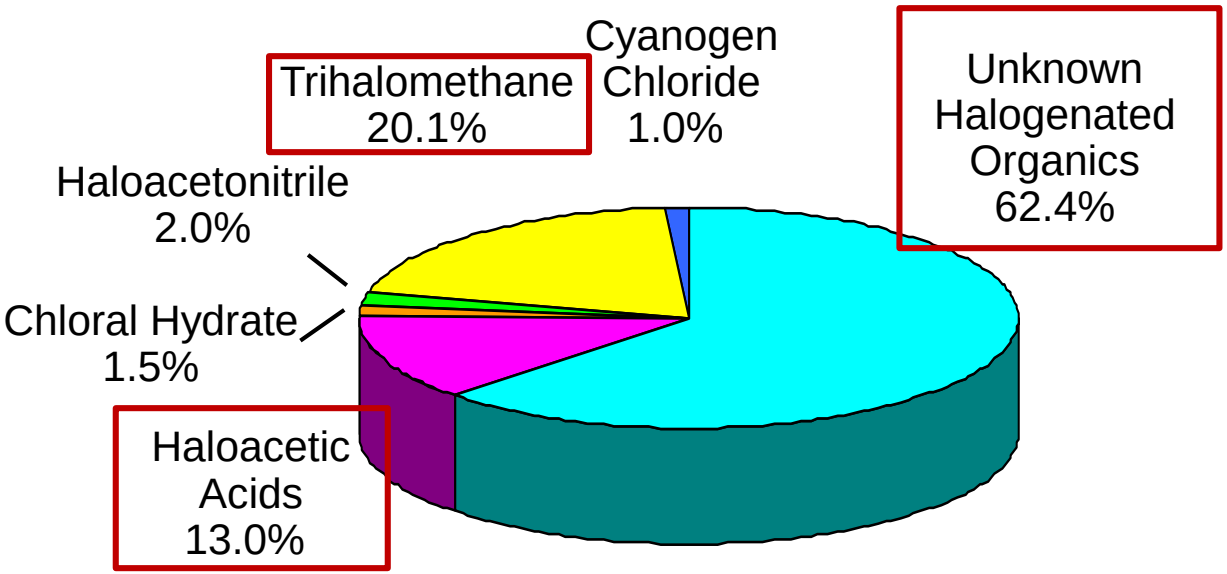
Disinfection Byproducts in Drinking Water

- Disinfection treatment is essential to eliminate waterborne disease-causing microorganisms
- Ozonation – bromate
- Chlorination (chlorine or chloramine)
  - Chlorite, chlorate
  - Trihalomethanes (THM) and haloacetic acids (HAAs)
- Highly regulated due to associated health issues
  - Chlorite: nervous system, affects fetal development, anemia
  - Bromate: carcinogenic
  - Chlorate: produce gastritis, blood diseases, and acute renal failure.
  - THM & HAAs: chronic exposure could increase risk of cancer
- Regulated under Safe Drinking Water Act
- EPA promulgated to the states

Occurrence of Disinfectant Treatment Byproducts

Haloacetic acids are formed when chlorine or other disinfectants react with naturally occurring organic and inorganic matter in water



Haloacetic acids (HAA5 and HAA9)

Acid	HAA	Formula	pK_a	Boiling Point (°C)
Monochloroacetic Acid	MCAA*	$ClCH_2CO_2H$	2.86	187.8
Dichloroacetic Acid	DCAA *	Cl_2CHCO_2H	1.25	194
Trichloroacetic Acid	TCAA *	Cl_3CCO_2H	0.63	197.5
Monobromoacetic Acid	MBAA *	$BrCH_2CO_2H$	2.87	208
Dibromoacetic Acid	DBAA *	Br_2CHCO_2H	1.47	195
Tribromoacetic Acid	TBAA**	Br_3CCO_2H	0.66	245
Bromochloroacetic Acid	BCAA**	$BrClCHCO_2H$	1.39	193.5
Chlorodibromoacetic Acid	CDBAA**	Br_2ClCCO_2H	1.09	NA
Bromodichloroacetic Acid	BDCAA**	Cl_2ClCCO_2H	1.09	NA

*HAA5; **HAA9

Disinfectant Byproducts (DBPs) Regulation

- Total Trihalomethanes (TTHMs) in 1970s
- 1998 U.S. EPA Stage 1 Disinfectants/Disinfection Byproducts (D/DBP) Rule:
  - Seven new regulations, including HAA5 and bromate
  - Monitoring of HAA5 at all plants that disinfect with chlorine
  - Report total MCAA, MBAA, DCAA, DBAA, and TCAA
  - Maximum Contamination Level (MCL) = 0.060 mg/L annual average
  - MCL Goal (MCLG): DCAA should not be present; TCAA < 0.030 mg/L
- 2006 U.S. EPA Stage 2 D/DBP Rule: Reduced MCLG
  - Total HAA5 MCL < 0.060 mg/L
  - MCAA < 0.07 mg/L; TCAA < 0.02 mg/L
  - DCAA should not be present

Summary of EPA Methods for HAAs (& Bromate, Dalapron)

Technique	EPA Method	Thermo Scientific™ Dionex™ IonPac™ Columns	MDL (ppb)
1) Liquid/Liquid Extraction 2) Derivitization 3) GC-ECD	552.2 552.3	GC-ECD	Mono: 0.13–0.20
			Di: 0.02–0.08
			Tri: 0.03-0.10
IC-MS, IC-MS/MS	557	Thermo Scientific™ Dionex™ IonPac™ AG24 precolumn + Thermo Scientific™ Dionex™ IonPac™ AS24 separation column (2 mm i.d.)	Mono: 0.06–0.20
			Di: 0.02–0.11
			Tri: 0.04–0.09
2D-IC Suppressed Cond. (direct)	Pending through 302.0, 314	First dimension: Dionex IonPac AG24A precolumn + Dionex IonPac AS24A separation column (4 mm i.d.)	Mono: 0.17–0.45
			Di: 0.06–0.13
		Second dimension: Thermo Scientific™ Dionex™ IonPac™ AG26 precolumn + Thermo Scientific™ Dionex™ IonPac™ AS26 separation column(0.4 mm i.d.)	Tri: 0.08–0.27

U.S. EPA Method 557

Suppressed ion chromatography with MS or MS-MS detection

- Direct injection method with matrix diversion
- Eliminates liquid-liquid extraction and labor intensive derivatization
- Eliminates co-elution issues because MS is a selective detector
- MS/MS provides molecular information assuring confirmation of analyte
- Fully automated
- Recovery > 90%

A Complete Family of Ion Chromatography Systems

Thermo Scientific Dionex ICS-900 Starter Line Ion Chromatography System

Thermo Scientific Dionex ICS-1100 Basic Integrated Ion Chromatography System

Thermo Scientific Dionex ICS-1600 Standard Integrated Ion Chromatography System

Thermo Scientific™ Dionex™ ICS-2100 Reagent-Free™ Ion Chromatography (RFIC™) System

Thermo Scientific™ Dionex™ ICS-4000 Capillary HPIC™ Ion Chromatography System

Thermo Scientific™ Dionex™ ICS-5000⁺ HPIC™ Ion Chromatography System

RFIC

HPIC

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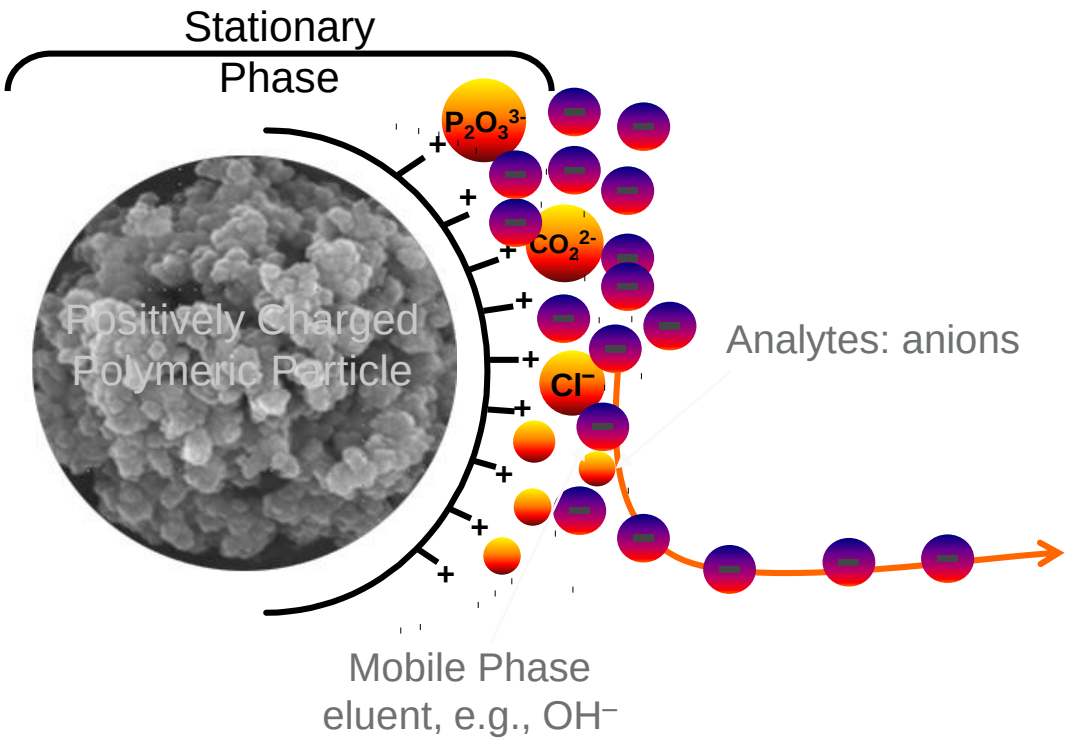
Ion Chromatography: Anion-Exchange Mechanism

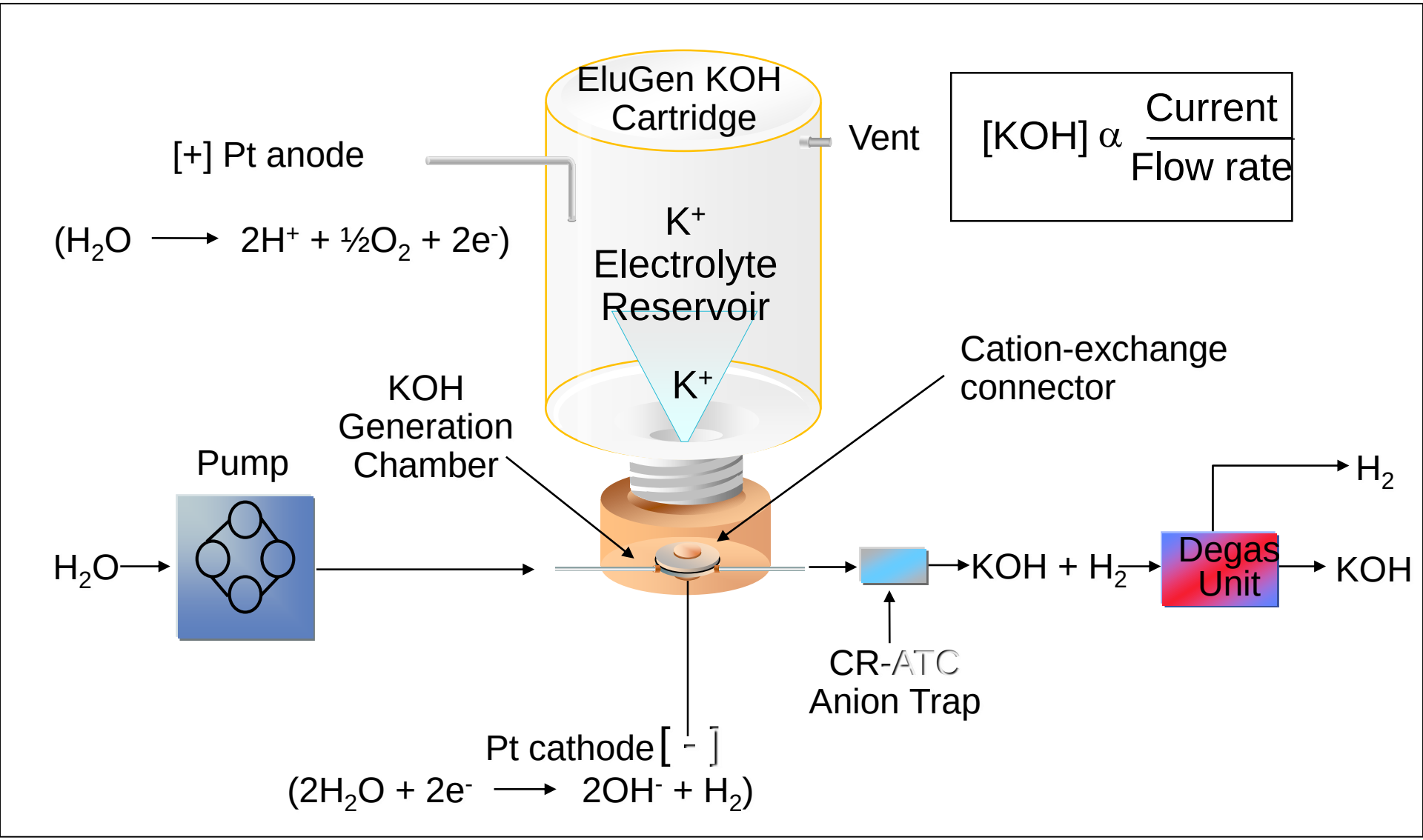


Advantages of IC

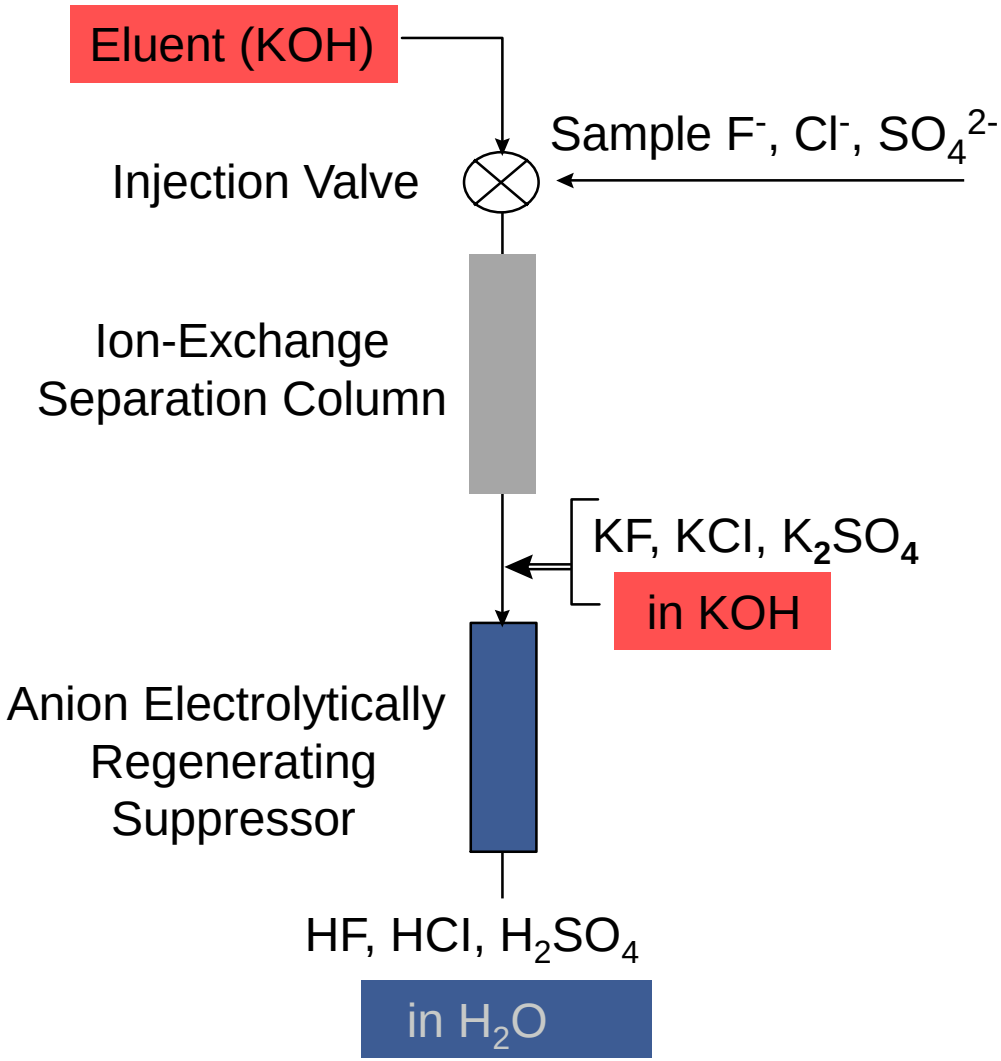
- ✓Direct method
  - – No chemical derivitization
- ✓Excellent selectivity
- ✓High sensitivity
  - – low chemical noise
- ✓Ideal for separations of small polar compounds
- ✓Low cost
  - – No solvent needed

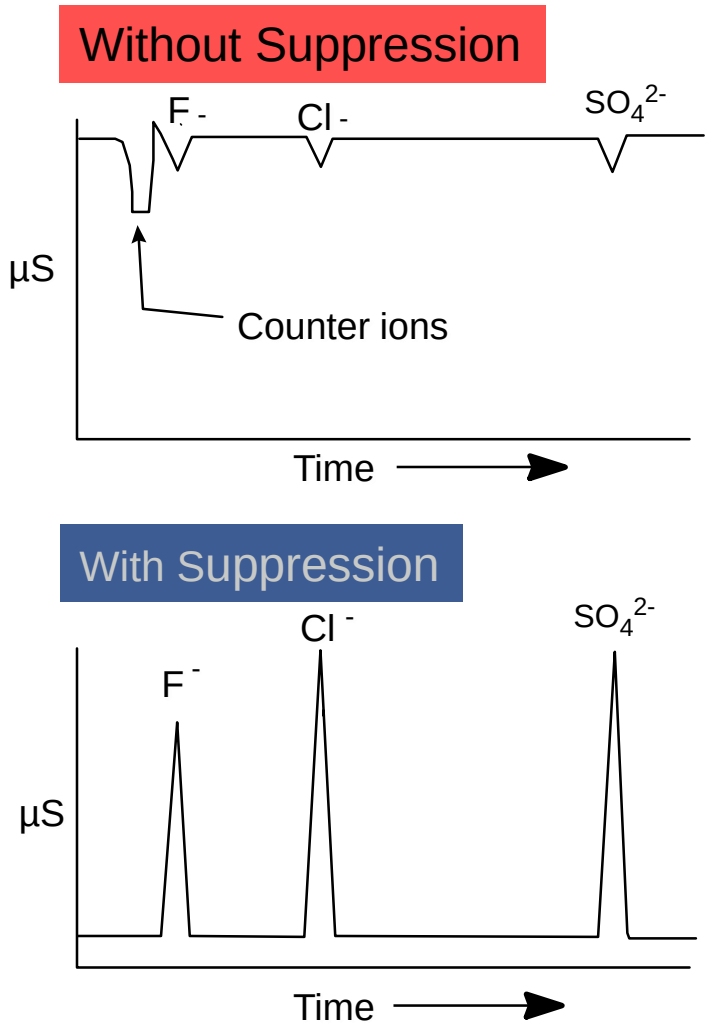
IC provides needed sensitivity and selectivity

Hydroxide Eluent Generation for Anion Analysis



Advantages of Suppressed Conductivity





Dionex ICS-5000^{+} HPIC IC System

Dionex ICS-5000^{+} HPIC

Highly Versatile Modular Design

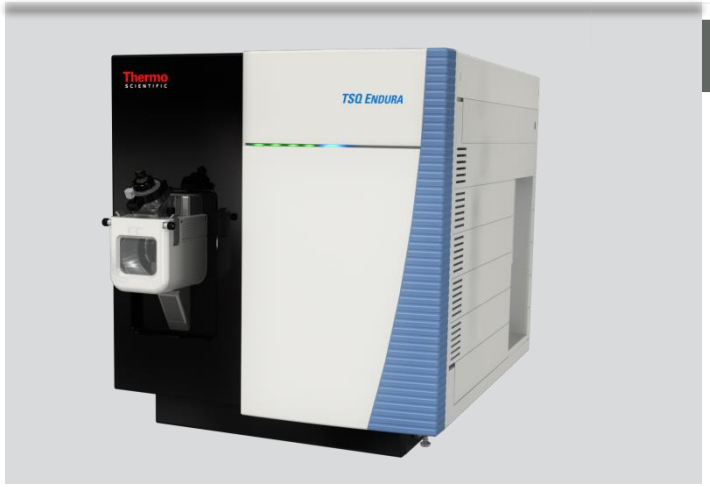
- Dual Reagent-Free IC system
- Improved performance in sensitivity, noise reduction, stable, and ease of use
- Increased temperature control for HAA applications
- Supports smaller particle separation columns and all column formats
- Supports multiple detection techniques

IC Conditions

Retention Time (min)	[KOH] mM
0.0	7.0
15.1	7.0
30.8	18.0
31	60
46	60
47	7.0
58	7.0

Column	Dionex IonPac AG24 (2×50mm), IonPac AS24 (2×250mm)
Suppressor	Dionex AERS 500, 2 mm
Column Temperature	15 °C
Injection Volume	100 µL
Flow Rate	0.3 mL/min KOH gradient, electrolytically generated

TSQ Quantiva and TSQ Endura Overview



TSQ Endura

Extreme Quantitative Value

- Best-in-class performance
- Unprecedented usability
- Exceptional robustness

TSQ Quantiva

Extreme Quantitative Performance

- Attogram sensitivity
- Unprecedented usability
- Exceptional robustness

Experimental Details

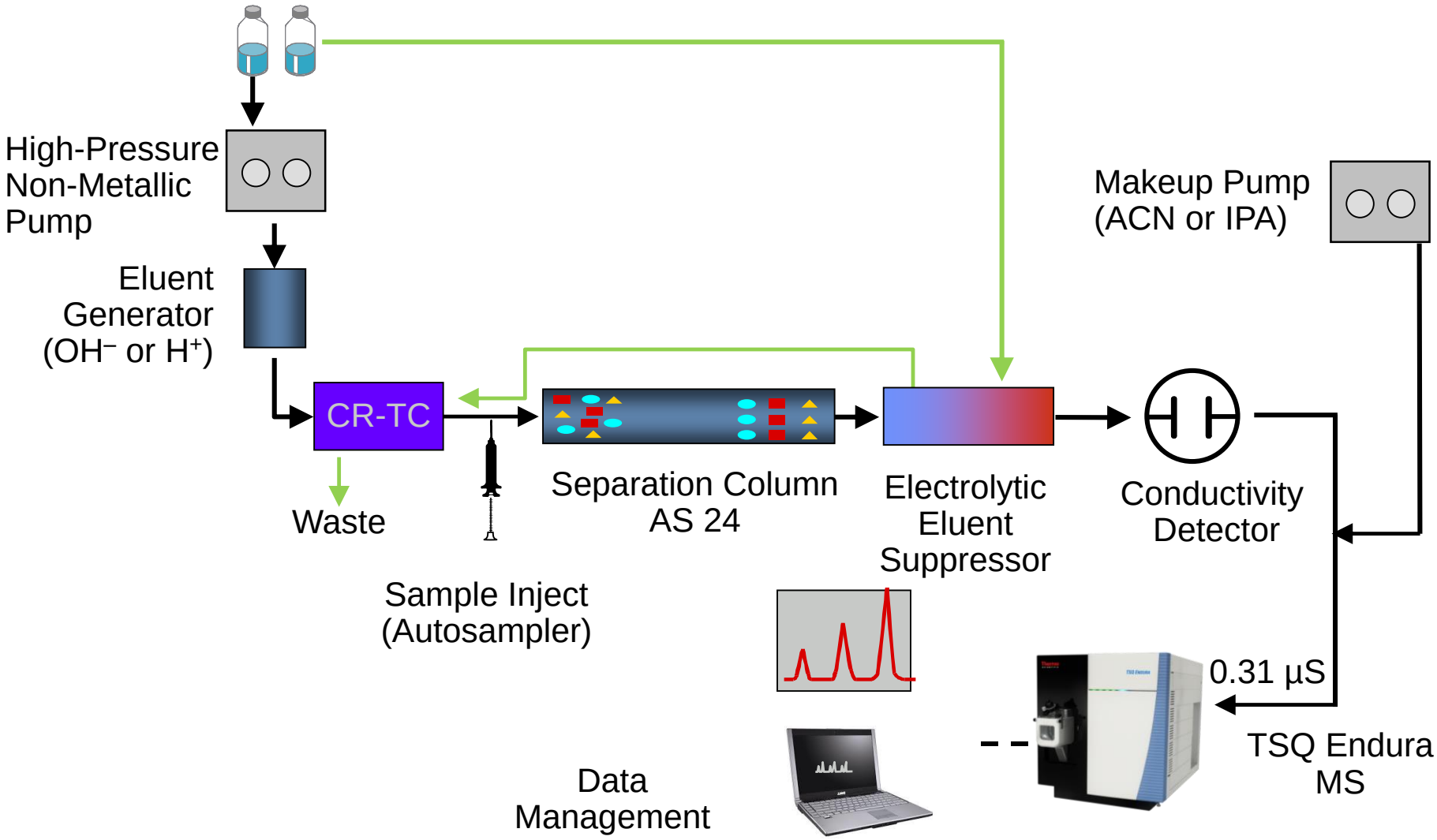
- Dionex ICS 5000^{+} HPIC coupled to a Thermo Scientific™ TSQ Endura™ MS
- Assay – Halo Acetic Acids
  - EPA method 557
  - Regulated compounds, disinfection byproducts
  - Calibration curve ranged from 0.25-20ppb
  - Who is interested in HAAs? “Anyone who drinks water!” – Richard Jack
- EPA regulates 5 HAAs*, but there are currently 9 total that are of interest. This analysis contains all 9.
  - MCAA Monochloro AA*
  - DCAA Dichloro AA*
  - TCAA Tricloro AA*
  - MBAA Monobromo AA*
  - DBAA Dibromo AA*
  - TBAA Tribromo AA
  - BCAA Bromochloro AA
  - DBCAA Dibromochloro AA
  - DCBAA Dichlorobromo AA

Mass Spectrometer Conditions

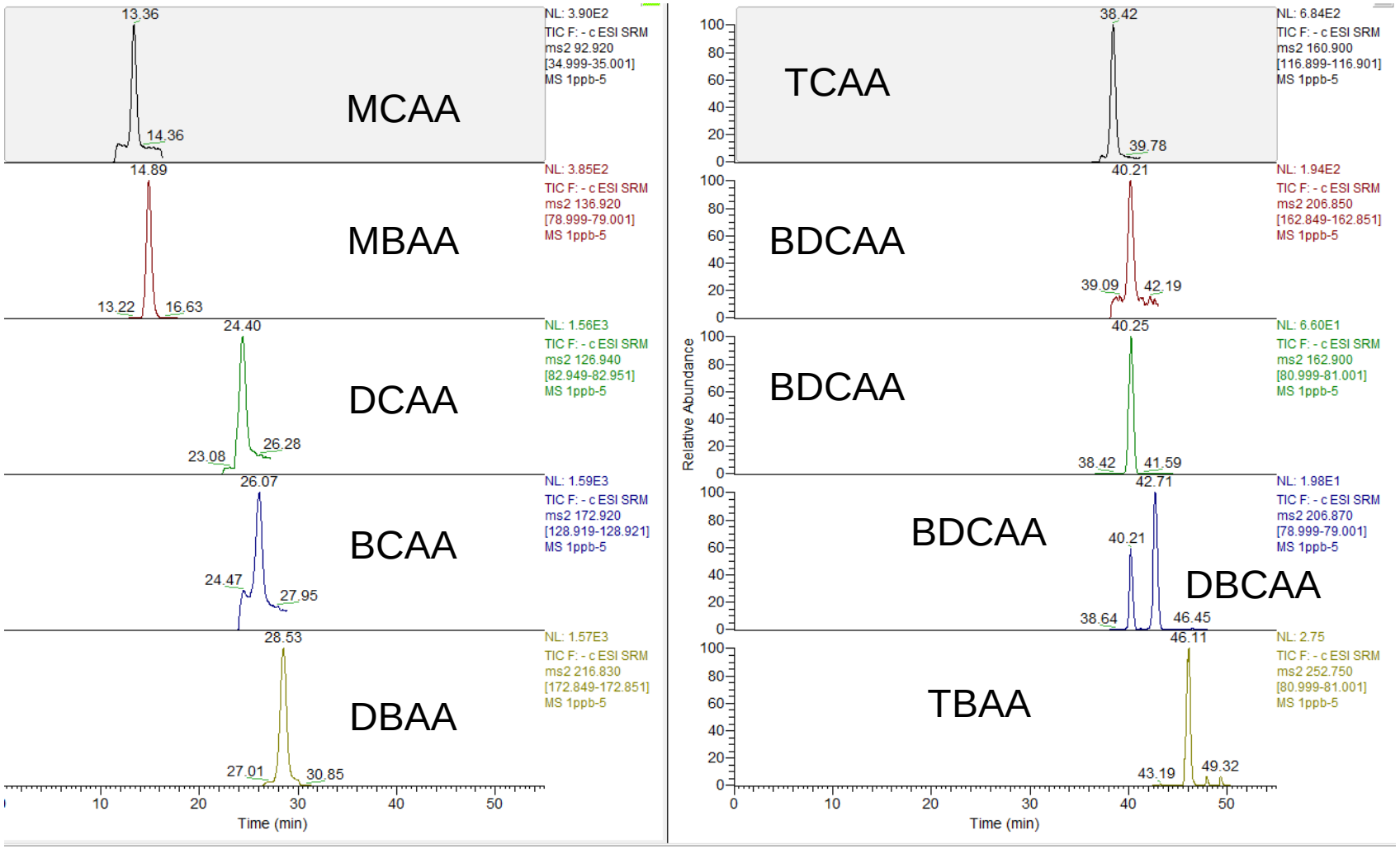
Parameter	Value
Ion Source Polarity	Negative Ion Mode
Spray Voltage	3200 V
Vaporizer Gas Pressure	45 units N_2
Auxiliary Gas Pressure	10 units N_2
Capillary Temperature	200 C
Vaporizer Temperature	200 C
Collision Gas Pressure	1.5 mTorr Argon
Ion Cycle Time	0.5 seconds

Analyte	Q1 (m/z)	Q3 (m/z)	RF lens (V)	CE (V)
MCAA	92.9	35.0	67	10
MBAA	136.9	79.0	60	13
DCAA	126.9	82.9	70	10
DBAA	216.8	172.8	72	12
BCAA	172.9	128.9	70	11
TCAA	160.9	116.9	45	8
BDCAA	162.9	81.0	60	10
DBCAA	206.9	81.0	90	16
TBAA	252.8	81.0	70	17
Dalapon	140.9	96.8	56	7
Bromate	126.9	110.9	90	22
MCAA-ISTD	94.0	35.0	67	10
MBAA-ISTD	138.0	79.0	60	13
DCAA-ISTD	128.0	84.0	70	10
TCAA-ISTD	162.0	118	45	8

IC-MS Flow Diagram



1ppb HAA standard, mixture of 9 HAAs



LSSM of HAA, Dalapon and Bromate 20ppb spike

Bromate

Dalapon

DCAA

BCAA

DBAA

TCAA

DCBAA

DBCAA

TBAA

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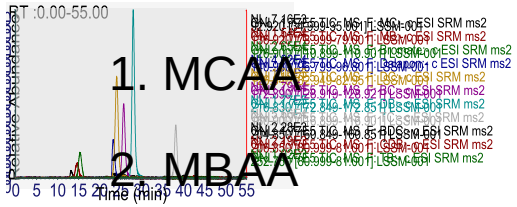
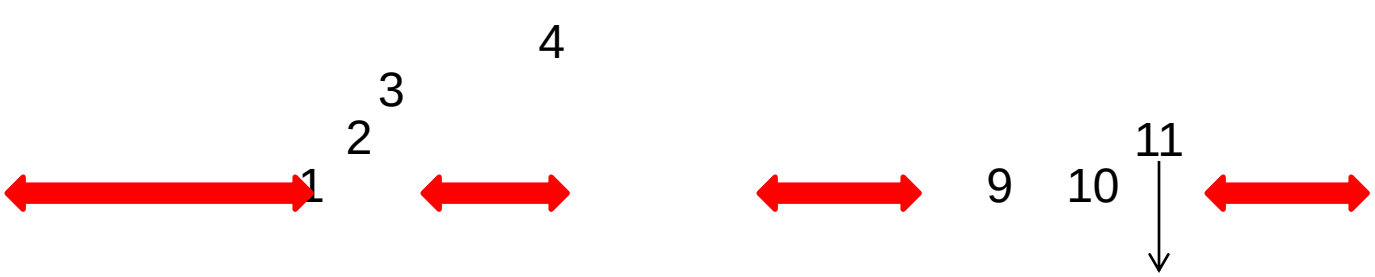
Overlaid Chromatograms with Divert Windows



1. MCAA
2. MBAA
3. Bromate
4. Dalapon
5. DCAA
6. BCAA
7. DBAA
8. TCAA
9. DCBAA
10. DBCAA
11. TBAA



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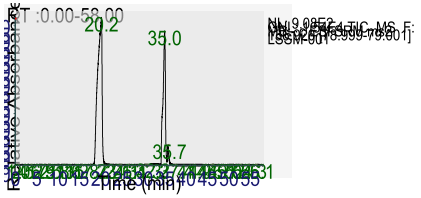
Divert to waste, eliminates salts from matrix



Cl^-

CO_3^{2-}
SO_4^{2-}

NO_3^-

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Method Detection Limits for HAAs by ICMS

Analyte	Calculated MDL (ppb)	EPA Method 557 MDL (ppb)	EPA Method 552.2 MDL (ppb)
MCAA	0.105	0.20	0.273
MBAA	0.104	0.064	0.204
DCAA	0.044	0.055	0.242
DBAA	0.021	0.015	0.066
BCAA	0.059	0.11	0.251
TCAA	0.033	0.090	0.079
BDCAA	0.141	0.050	0.091
DBCAA	0.214	0.041	0.468
TBAA	0.159	0.067	0.820
Dalapon	0.050	0.038	N/A
Bromate	0.059	0.020	N/A

Conclusions

- Demonstrated the analysis of 9 HAAs, Bromate and Dalapon using IC coupled to MS/MS
- Detection limits exceed the requirements of the EPA method
- No derivitization steps required prior to analysis
- Low chemical noise with suppressor to increase sensitivity, eliminate ion suppression, and enable compatibility with MS
- Ion Chromatography offers excellent separations and selectivity for HAAs
- Dionex ICS-5000+ offers temperature control which is critical for this method
- No sample prep, besides addition of internal standards for analysis
- MS/MS offers specificity and sensitivity over single quadrupole methods
- TSQ Endura offers excellent performance at an attractive price point

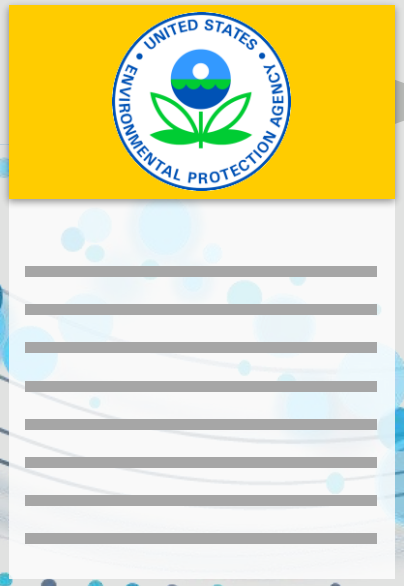
Future Application Plans for ICMS

- Polar Pesticides in Drinking Water and Food
  - AMPA, Glyphosate, Phosphonic acid, Perchlorate, Fosetyl-Al, Maleic hydrazide, HEPA, Ethephon, MPPA, Glufosinate, N-acetyl-glufosinate
- Perchlorate in Drinking Water
- Additional Disinfection byproducts including HAAs of Iodine

Targeted Quantitation: EPA 543 on TSQ Quantiva MS and EQuan MAX Plus

EPA 543

Current Title:
Determination of Selected Organic Chemicals in Drinking Water by On-Line Solid Phase Extraction-Liquid Chromatography / Tandem Mass Spectrometry (On-line SPE-LC/MS/MS)



- First EPA promulgated method using Online SPE (Themo Scientific™ EQuan MAX Plus system)
- Online SPE Analog of EPA 540
- Currently in Draft Form Status, scheduled release Sept 2014
- Thermo has been testing the method in conjunction with the US EPA Office of R&D, National Exposure Research Laboratory – **Jody Shoemaker – EPA Cincinnati, OH.**
- Analytes:
  - 3-Hydroxycarbofuran
  - Bensulide
  - Fenamiphos
  - Fenamiphos sulfone
  - Fenamiphos sulfoxide
  - Tebuconazole
  - Tebufenozide

EPA 543 Method

- EQuan MAX Plus system with TSQ Quantiva MS
- Load Column – Waters Oasis HLB* (Alternative Thermo Scientific column being tested)
- LC Column –aQ 100 x 2.1mm 2.6 mm
- 2mL injection volume
- Drinking water matrix

*Required by the EPA method.

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EQuan MAX Plus

For targeted quantitation (TSQ)

or

Targeted/non-targeted screening and quantitation using High Resolution Accurate Mass (Orbitrap platform)

EQuan MAX Plus: What is it ?

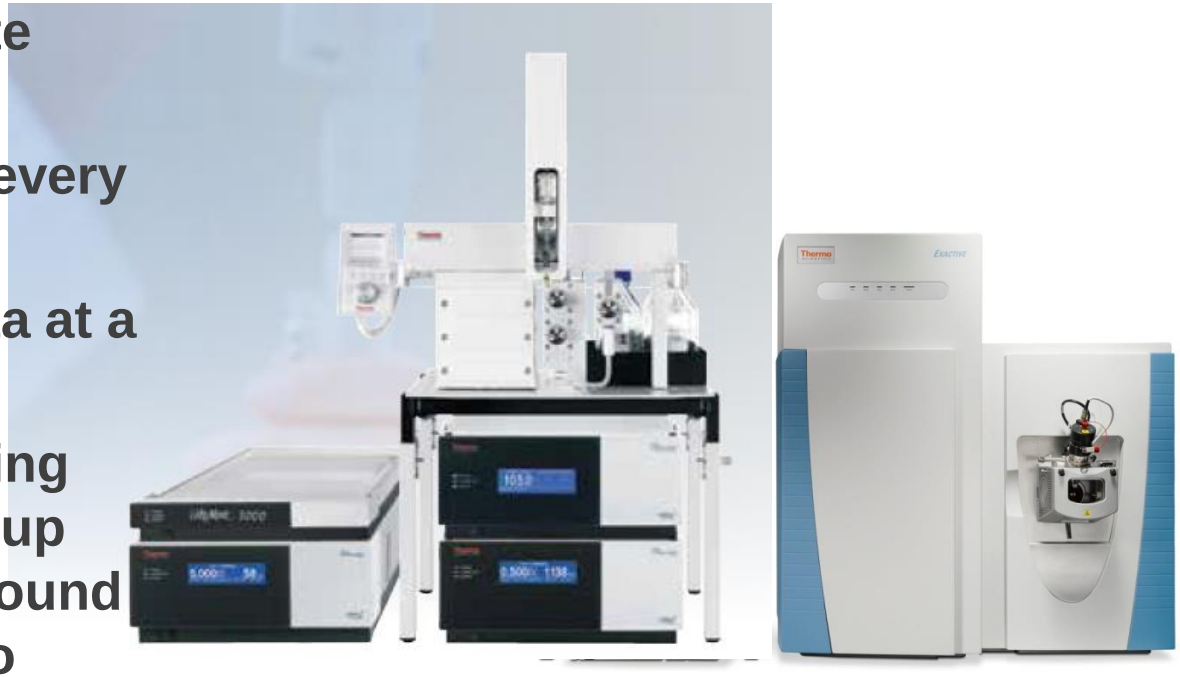
- Turnkey method for assaying environmental water samples (pesticides, antibiotics, etc.) at low ppt levels
  - **On-line sample clean-up and preconcentration**
    - **2 Columns : Loading and Analytical**
    - **2 pumps**
  - **High injection volumes**
    - **1mL-20mL**
  - **Standard injection volumes**
    - **1-100 uL**

EQuan MAX Plus: Targeted Quantitation

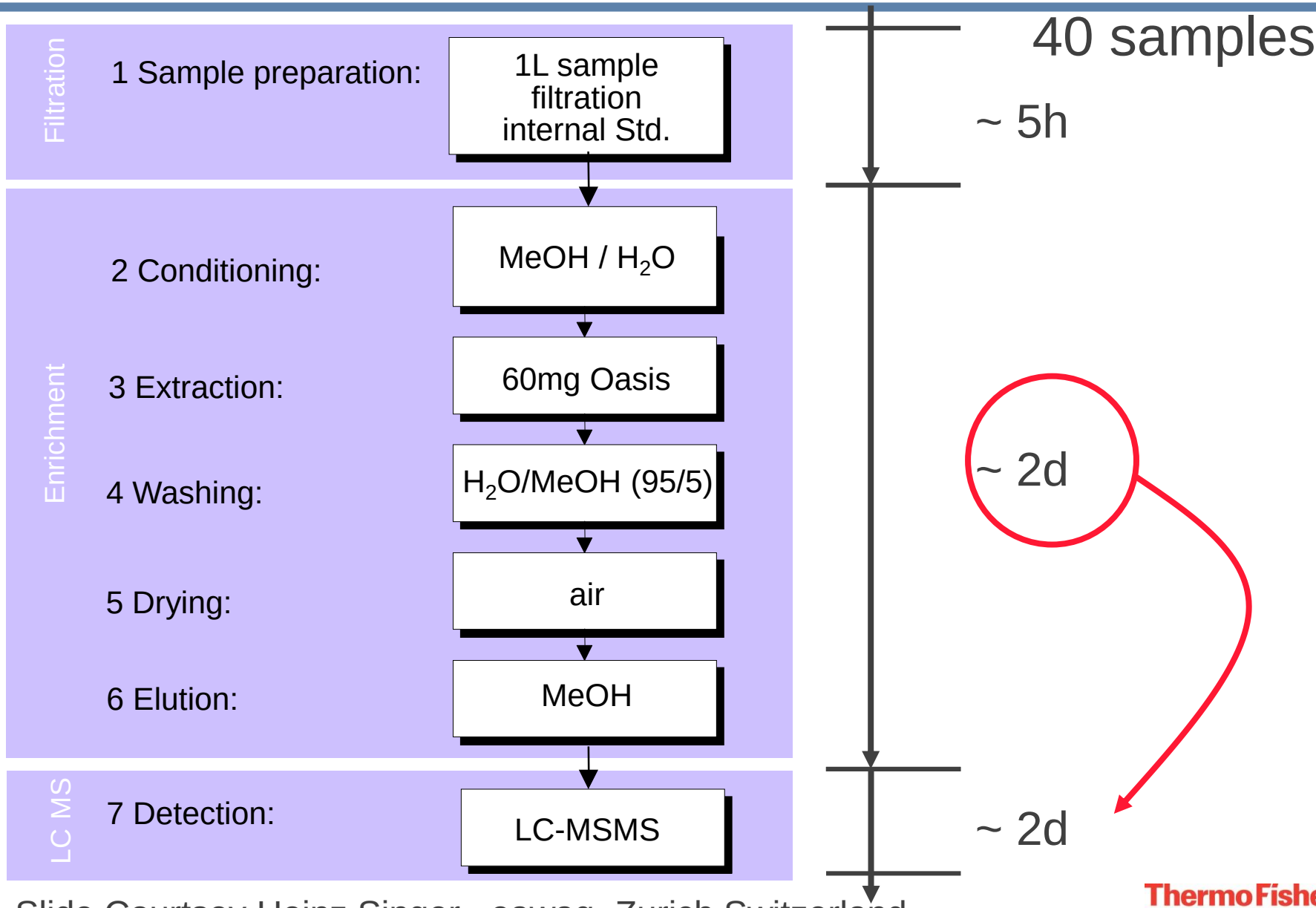
- Couple EQuan MAX Plus with any TSQ Quantum from Thermo Scientific for the most sensitive and selective experiments.
- **Fast Positive Negative Switching**
  - **25ms**
- **TraceFinder Software**
  - **Built in SRM parameters**
  - **Built in EQuan Methods**
- **TSQ Quantum Access MAX**
- **TSQ Endura**
- **TSQ Quantiva**

EQuan MAX Plus: Non-targeted screening and Quantitation

- Couple EQuan MAX Plus with the Exactive Orbitrap instruments (Exactive Plus or Q-Exactive Plus).
- **High Resolution Accurate Mass (HRAM)**
- **All ions are collected in every experiment.**
  - **Re-interrogate your data at a later time**
- **Quantitation and screening methods are easy to set up since there are no compound dependant parameters to optimize.**

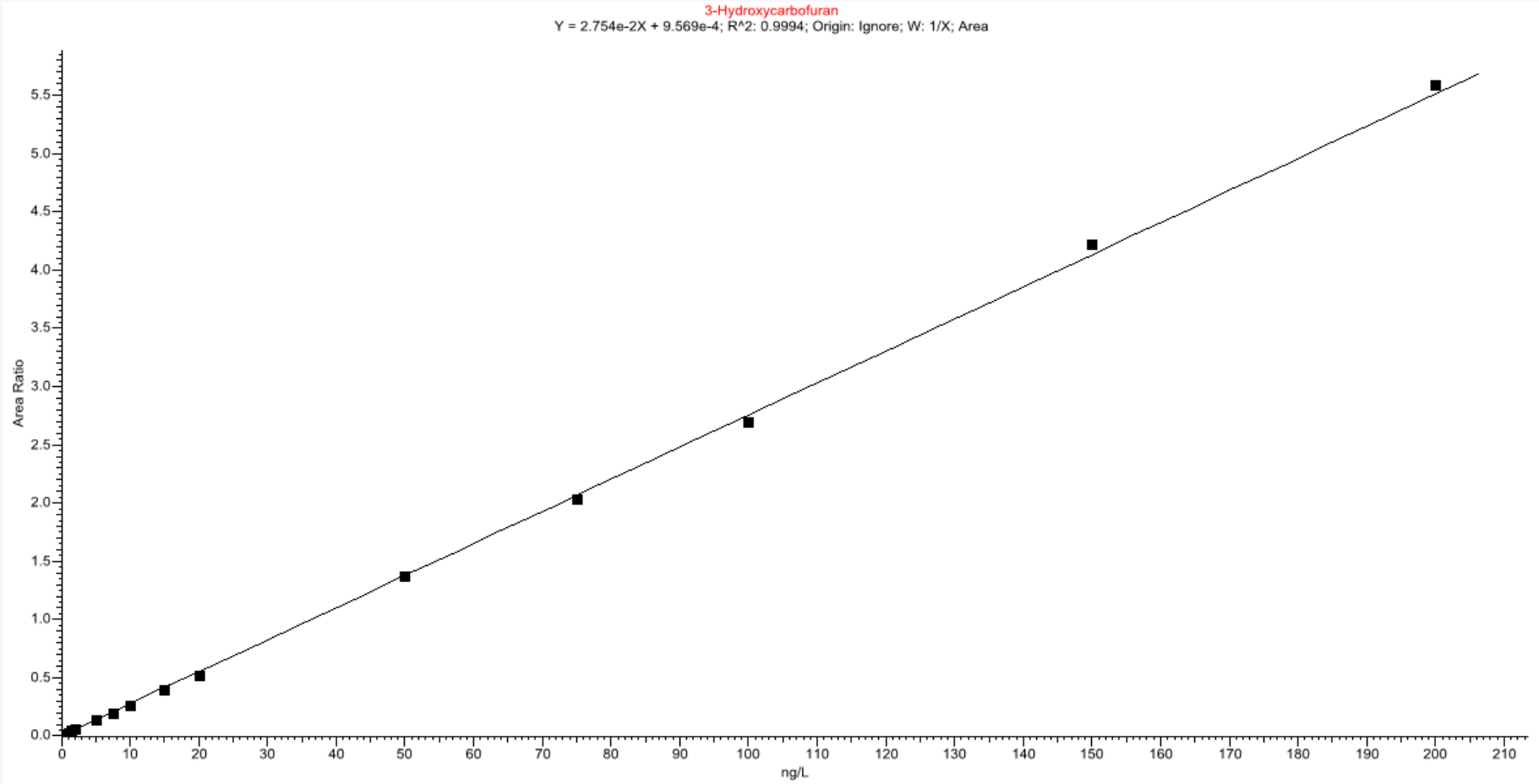


SPE - standard enrichment procedure



Slide Courtsey Heinz Singer –eawag, Zurich Switzerland

Calibration Curve for 3-Hydroxycarbofuran



Calibration Range = 0.5-200 ng/L

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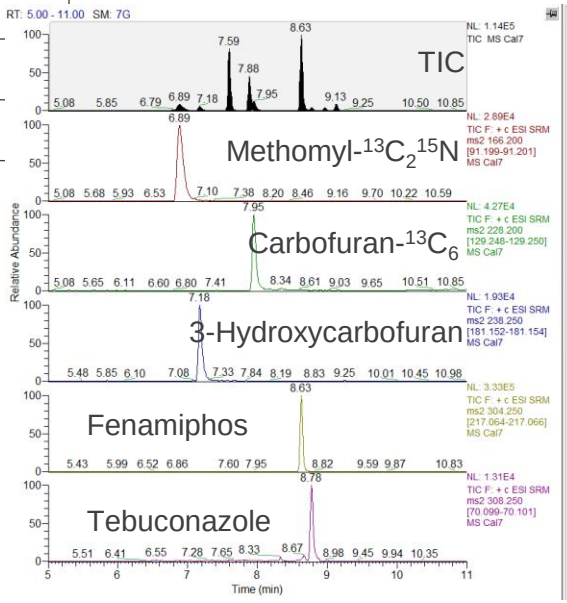
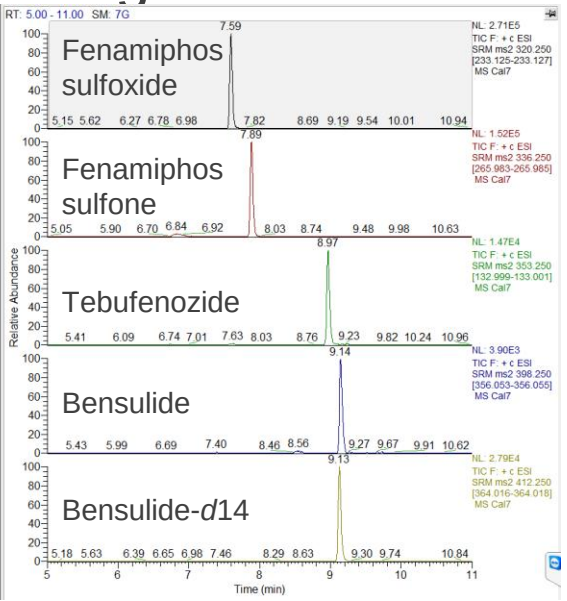
EPA 543 Detection Limits and Chromatogram

Compound	LCMRL (ng/L)	Detection Limit (ng/L)
3-Hydroxycarbofuran	< 0.5	0.31
Bensulide	2.1	0.71
Fenamiphos	<0.2	0.061
Fenamiphos sulfone	<0.5	0.11
Fenamiphos sulfoxide	<0.5	0.10
Tebuconazole	0.46	0.41
Tebufenozide	14	1.2

Mid Level Calibrator, 6 or 15 ng/L





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Thank you!

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The world leader in serving science

WS71333-EN 1014S