

Determination of Organochlorine Pesticides and Polychlorinated Biphenyls Using GC/MS/MS Operated in the MRM Mode

Brahm Prakash, William Lipps

■ Introduction

The determination of chlorinated pesticides (OCPs) and polychlorinated biphenyls (PCBs) in environmental matrices is a common analysis in most environmental laboratories. These compounds are typically analyzed by employing solid phase or liquid-liquid extraction with methylene chloride, concentration, solvent exchange into hexane, and interference removal using acid, copper, or column chromatography. Analysis is done using gas chromatography (GC) with electron capture detection (ECD) and requires confirmation of every detected component on another, dissimilar GC column. However, GC-ECD techniques are prone to positive and negative bias in complex matrices, resulting in unnecessary cleanup costs and/or violations of NPDES permits. Clearly, a new method for pesticides and PCBs, based on modern GCMS technology is needed.

This paper describes use of a triple quadrupole GC/MS/MS method using Multiple Reaction Monitoring (MRM) mode for sensitive and selective detection and quantitation of Organochlorine pesticides and PCBs. A database with optimized MRM transitions for all of the OCPs and PCBs, including relative retention times for all components, makes method setup possible within minutes. The use of GC/MS/MS MRM mode provides enhanced selectivity, specificity and sensitivity in complex matrices with potential co-eluting interferences¹.

This paper presents all instrument operating conditions and instrument method performance statistics, including method linearity, accuracy, precision, and instrument detection limits for all compounds.

■ Discussion

Chlorinated pesticides and polychlorinated biphenyl (PCB) congeners (known collectively as Aroclor) are among the most difficult to measure environmental organic compounds. The difficulty is primarily because they are found at very low concentrations. The EPA approved method for Organochlorine pesticides and PCBs in wastewater is EPA Method 608². Method 608 relies upon gas chromatography with electron capture detection (GC-ECD) to measure a targeted list. GC-ECD is one of the few techniques available capable of detecting halogenated compounds at very low concentrations. GC-ECD is a non-specific detection technique that can produce a signal for non-target compounds. As a result, when using GC-ECD for pesticides and PCBs in environmental samples, other components in the sample can be detected and interfere with both identification and quantitation³. Target compounds are identified by retention time. Aroclors are a mixture of hundreds of different congeners requiring identification be made by the analyst visually comparing the chromatography of the unknown with the chromatography of the standards. (See Figure 1 for an example of an Aroclor chromatogram).

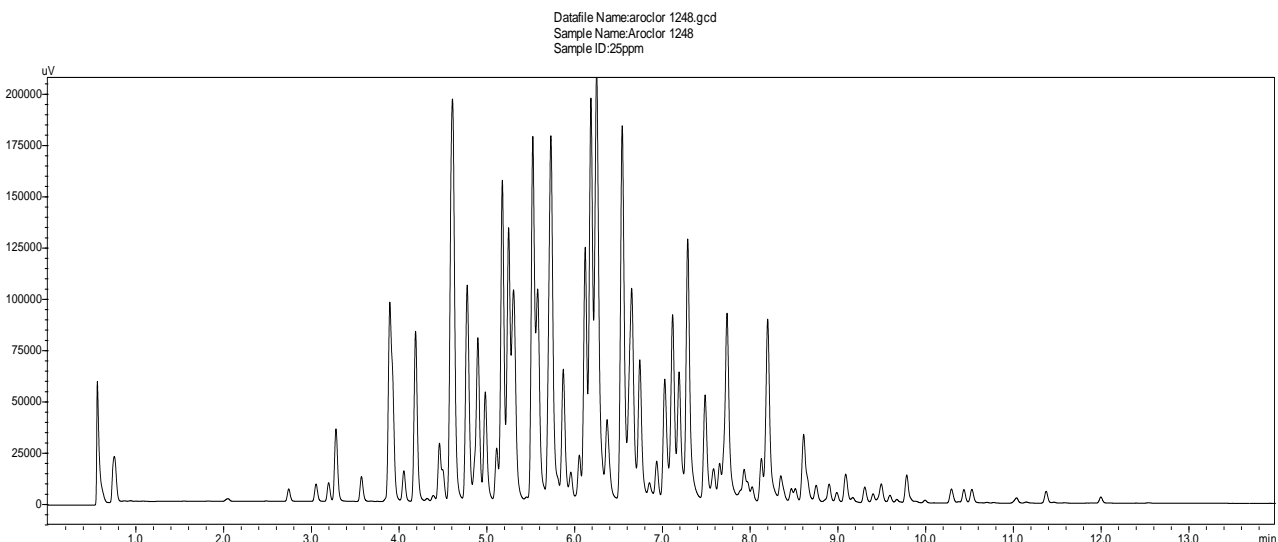


Figure 1: Aroclor 1248 chromatogram

GC-ECD Suffers from Matrix Interferences

The matrix itself can have a profound impact on the chromatography and on the response of the ECD. High levels of non-target components in the matrix can co-elute. False positives result if the co-eluting compound responds to the detector, whereas false negatives result if the co-eluting compound quenches the ECD signal. The EPA requires that any detected compound be analyzed again on a different chromatography column to “confirm” the identity of every detected component. This second column confirmation means that every sample be either analyzed twice, or that the laboratory instrument is equipped with two columns and two detectors. The second column confirmation may help to recognize interferences, but cannot guarantee interferences are corrected⁴.

Second column confirmation for all positive GC-ECD peaks does not guarantee positive identification or quantitation of the pesticides. Just as there may be co-elution on the primary column, there can be co-elution on the second column as well. Hydrocarbons and the presence of other components (such as PCBs) can interfere.

Single Quadrupole GCMS Is Not Sensitive Enough

Method 608 allows the use of mass spectrometry (MS) as a confirmatory detector provided the compound concentration is high enough to be measured. Traditionally, commercially available gas

chromatography-mass spectrometry (GCMS) systems were not sensitive enough to detect the pesticides and/or PCBs at the concentrations being measured. But the sensitivity of GCMS has increased dramatically since Method 608 was written. New GCMS technology can be run in selected ion monitoring mode (SIM), greatly increasing the sensitivity. In addition, newer tandem GCMS technology eliminates almost all noise, increasing the sensitivity of the detector 5 - 10 times more than that of SIM. With this new tandem GCMS technology (also known as GC/MS/MS or Triple Quadrupole GCMS), GC-ECD detection limits are possible. Even better, this new technology almost completely eliminates matrix interferences, and provides qualitative information about the detected analytes.

Triple Quadrupole GCMS Is Very Sensitive and Interference Free

Triple quadrupole mass spectrometry is the linking together of two quadrupoles. Ions are separated in the first quadrupole, fragmented further in a collision cell, and the product ions are separated and analyzed by a second quadrupole. This technique eliminates matrix interferences, making it highly selective and extremely sensitive. Quantitative and qualitative analyses can be made in at least four modes, as shown in Table 1. Faster scanning analyzers, such as the Shimadzu GCMS-TQ8040, are capable of Scan/MRM and/or Scan/SIM all in a single method.

Table 1: Analysis modes for tandem GCMS analyzers

Analysis Mode	First Quadrupole	Second Quadrupole
Full Scan (same as single quadrupole GC-MS)	off	Scan
Selected Ion Monitoring (SIM)	off	SIM
Scan/SIM	Scan	SIM
Multiple Reaction Monitoring (MRM)	SIM	SIM
Scan/MRM	off/SIM	Scan/SIM

Multiple Reaction Monitoring (MRM) eliminates matrix noise and allows only the selected product ion through the second quadrupole. Although the sensitivity is actually less, the noise is reduced, increasing the signal-to-noise ratio. Figure 2 shows a schematic of tandem quadrupoles and how noise is eliminated. Figure 3 shows a SIM and MRM chromatogram showing the decrease in noise and signal and the corresponding increase in the MRM signal-to-noise ratio. MRM detection limits are usually 5-10 times lower than SIM detection limits.

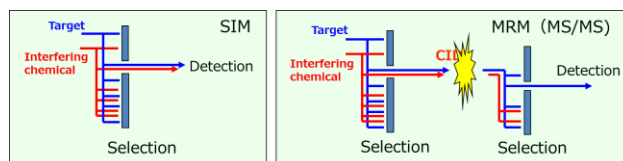


Figure 2: Schematic of a triple quadrupole analyzer and how it eliminates interference

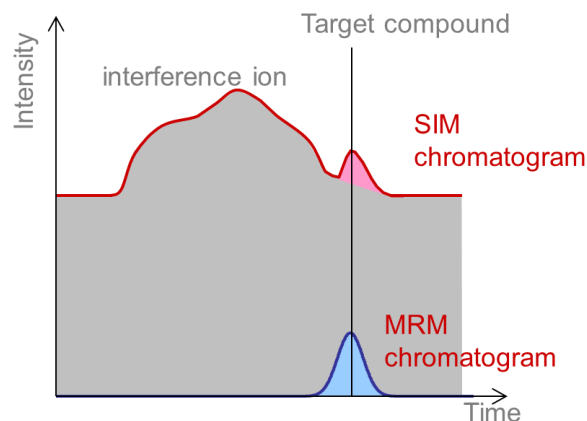


Figure 3: Example of a SIM and MRM chromatogram showing improvement of MRM S/N ratio

In a comparison of GC-ECD and HRGC/MSMS, McAteer and Hughes⁵ found significant bias between organochlorine pesticides results. Table 2 provides some of their data, showing results for 4, 4-DDT, 4, 4-DDD and 4, 4-DDE. The samples were high in PCBs (determined by Method 608) and Total Petroleum Hydrocarbons (TPH). Since the HRGC/MSMS is essentially interference free, it's assumed results from this instrument are correct and the results from the GC-ECD method are biased.

Why Do We Need a New PCB Method?

PCBs are some of the most stable organic compounds known. There are 209 distinct PCB compounds (known as congeners)⁶, which could have anywhere from 1 to 10 chlorine atoms on a biphenyl molecule. PCBs occur as a mixture of congeners, which were sold commercially as Aroclors. Method 608 lists seven separate PCBs that must be analyzed. Method 608 identifies PCBs by their chromatographic pattern as compared to injection of Aroclor standards under the same chromatographic conditions. The problem is that PCBs can weather at different rates, thereby affecting pattern recognition, and cause analysts to report Aroclors as not detected⁷.

Using GC/MS/MS for a New Pesticide and PCB Method

Triple quadrupole instruments are ideally suited for a new method to determine pesticides and PCBs and for replacing Method 608 for wastewater compliance monitoring. These instruments are affordable, have detection limits comparable to the ECD, yet can detect trace compounds in highly complex matrices with very little interference. This paper describes a Multiple Reaction Monitoring (MRM) instrument method for low-level detection of Method 608 pesticides and a selected group of PCB congeners.

Table 2: Comparison of ECD and HRGC/MSMS results in ug/kg

Compound	Instrument	Sample C1	Sample C2	Sample C3	Sample C4	Sample C5	Sample C6	Sample C7
4,4 - DDT	GC-ECD	29	49	150	180	28	5.7	440
	GCMSMS	0.014	0.014	0.014	0.014	3	0.014	0.5
4,4 - DDD	GC-ECD	14	33	2.9	4.9	5.1	0.43	17
	GCMSMS	28	35	12	9.7	18	0.51	31
4,4 - DDE	GC-ECD	3.2	1.2	1.1	1.6	4.4	0.42	6.5
	GCMSMS	2.4	6.7	9.3	5.6	5.0	0.13	6.3
Aroclors	GC-ECD	300	950	6500	1500	650	186	216
TPH	GC-FID	5700	5800	1500	1010	1010	96	1500

■ Experimental

This study was conducted using a Shimadzu GCMS-TQ8040 (Figure 4) configured with a Restek capillary column designed specifically for the analysis of semi-volatile analytes. The GC was operated in constant linear velocity mode, providing the best chromatographic resolution, symmetrical peak shapes, and enhanced sensitivity for the target compounds. A commercial mixture of 19 PCB congeners, 20 Organochlorine pesticides, five internal standards, and four surrogates was used to prepare calibration curves ranging from 0.5 - 200 ppb. The standards were prepared in a mixture of EPA method 625 acids and base-neutral target analytes to provide a better, more realistic, synthetic matrix.

Chromatographic conditions were established and the MRM method was optimized for each component. The instrument operating conditions are shown in Table 3.



Figure 4: Shimadzu GCMS-TQ8040

Table 3: GCMS-TQ8040 operating conditions

Instrument	GCMS-TQ8040
Column	SH-Rxi-5 MS, 30 m x 0.25 mm x 0.25 µm (Shimadzu PN 221-75940-15)
Oven Program	50°C, hold 0.5 minute, 28°C/minute to 265°C, 3°C/minute to 285°C, 25°C/minute to 330°C, hold 1.0 minute
Injector	Pulse Splitless (250kPa for 1.50 minutes, 2µL 275°C)
Carrier Gas	Helium Constant linear velocity mode, 43.5 cm/sec Total Flow 30 mL/min, Column Flow = 1.0 mL/min Purge Flow 3.0 mL/min
Interface Temperature	290 °C
Mass Spectrometer	GCMS-TQ8040
Ion Source Temperature	230 °C
MS Operating Mode	Acquisition Mode, MRM CID gas, Argon Solvent cut Time, 1.35 minutes Detector voltage absolute, 1.90kV Threshold = 0, Event time 0.200 sec
Analysis Times	17.65 minutes
GC Cycle Time	22.00 minutes

MRM Method Development

MRM transitions were monitored for each component. Quantitative and qualitative transitions were selected to provide maximum sensitivity and as independent confirmation of the compounds identity. The Ion Shield High Efficiency source minimized fragmentation even at 70 eV, providing an optimum abundance and transmission of ions

into the quadrupoles. Method settings were made to provide enough sensitivity to easily detect and quantify the target analytes at concentrations equal to or better than Method 608. MRM transitions and collision energies (CE) for each compound are shown in Table 4.

Table 4: GCMS-TQ8040 MRM transitions and collision energies

Component	Quantitative			Qualitative		
	Precursor	Product	CE (V)	Precursor	Product	CE (V)
2-Fluorophenol (IS)	112.00	64.20	18.0	92.00	64.20	6.0
Pentafluorophenol (SURR)	136.00	117.20	15.0	184.00	117.20	27.0
Nitrobenzene-d5 (IS)	82.00	54.20	15.0	128.00	82.30	15.0
2,4,5,6-tetrachloro-m-xylene (SURR)	244.00	209.10	15.0	171.00	136.20	15.00
4,4'-Dibromooctafluorobiphenyl (SURR)	456.00	296.00	27.0	296.00	246.10	24.0
Alpha-BHC	180.90	144.90	16.0	218.90	182.90	8.0
Gamma-BHC (Lindane)	180.90	144.90	16.0	218.90	182.90	8.0
Beta-BHC	180.90	144.90	16.0	218.90	182.90	8.0
Delta- BHC	180.90	144.90	16.0	218.90	182.90	8.0
Heptachlor	271.80	236.90	20.0	273.80	238.90	16.0
Aldrin	269.90	191.00	34.0	262.90	193.00	28.0
4,4'Dibromobiphenyl (SURR)	312.00	152.30	14.0	152.30	126.20	24.0
Heptachlor Epoxide (isomer B)	352.80	262.90	14.0	354.80	264.90	20.0
Trans-Chlordane	372.80	263.90	28.0	374.80	265.90	26.0
Cis-Chlordane	372.80	263.90	28.0	374.80	265.90	26.0
Endosulfan I	194.90	160.00	8.0	194.90	125.00	24.0
4,4'-DDE	246.00	176.00	30.0	317.90	248.00	24.0
p-Terphenyl-d14 (IS)	244.00	240.30	30.0	244.00	242.20	18.0
Dieldrin	276.90	241.00	8.0	262.90	193.00	34.0
Endrin	262.90	191.00	30.0	262.90	193.00	28.0
4,4'-DDD	235.00	165.00	24.0	237.00	165.00	28.0
Endosulfan II	194.90	160.00	8.0	194.90	125.00	24.0
Endrin Aldehyde	249.90	214.90	18.0	249.90	179.00	16.0
4,4'-DDT	235.00	165.00	24.0	237.00	165.00	28.0
Endosulfan Sulfate	271.80	236.90	18.0	386.80	252.90	16.0
Methoxychlor	227.10	169.10	24.0	227.10	212.10	14.0
Endrin Ketone	281.00	244.90	12.0	281.00	208.90	24.0
Decachlorobiphenyl (BZ#209) (IS)	497.70	427.80	30.0	499.70	429.80	30.0
Decafluorobiphenyl (IS)	214.00	179.10	18.0	178.00	160.60	9.0
2-Chlorobiphenyl (#1)	188.00	152.00	24.0	190.00	152.00	24.0
2,3-Dichlorobiphenyl (#5)	222.00	152.00	24.0	224.00	152.00	24.0
2,2',5-Trichlorobiphenyl (#18)	255.90	186.00	26.0	257.90	186.00	26.0
2,4',5-Trichlorobiphenyl (#31)	255.90	186.00	26.0	257.90	186.00	26.0
2,2',5,5'-Tetrachlorobiphenyl (#52)	289.90	219.90	26.0	291.90	221.90	26.0
2,2',3,5'-Tetrachlorobiphenyl (#44)	289.90	219.90	26.0	291.90	221.90	26.0
2,3',4,4'-Tetrachlorobiphenyl (#66)	289.90	219.90	26.0	291.90	221.90	26.0
2,2',4,5,5'-Petachlorobiphenyl (#101)	323.90	253.90	26.0	328.90	255.90	26.0
2,2',3,4,5'-Pentachlorobiphenyl (#87)	323.90	253.90	26.0	325.90	255.90	26.0
2,3,3',4',6-Pentachlorobiphenyl (#110)	323.90	253.90	26.0	325.90	255.90	26.0
2,2',3,5,5',6-Hexachlorobiphenyl (#151)	359.90	289.90	28.0	361.90	291.90	28.0
2,2',4,4',5,5'-Hexachlorobiphenyl (#153)	359.90	289.90	28.0	361.90	291.90	28.0
2,2',3,4,5,5'-Hexachlorobiphenyl (#141)	359.90	289.90	28.0	361.90	291.90	28.0
2,2',3,4,4',5'-Hexachlorobiphenyl (#138)	359.90	289.90	28.0	361.90	291.90	28.0
2,2',3,4',5,5',6-Heptachlorobiphenyl (#187)	393.80	323.90	28.0	395.80	325.90	28.0
2,2',3,4,4',5',6-Heptachlorobiphenyl (#183)	393.80	323.90	28.0	395.80	325.90	28.0
2,2',3,4,4',5,5'-Heptachlorobiphenyl (#180)	393.80	323.90	28.0	395.80	325.90	28.0
2,2',3,3',4,4',5'-Heptachlorobiphenyl (#170)	393.80	323.90	28.0	395.80	325.90	28.0
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (#206)	461.70	391.80	30.0	463.70	393.80	30.0

Calibration

A 9-point calibration curve of 0.5 - 200 ppb was analyzed using the conditions described in Table 3. The curves of all 48 components were evaluated using linear regression and %RSD of the calculated Response factors. A MRM chromatogram from a mid-point standard is shown in Figure 5.

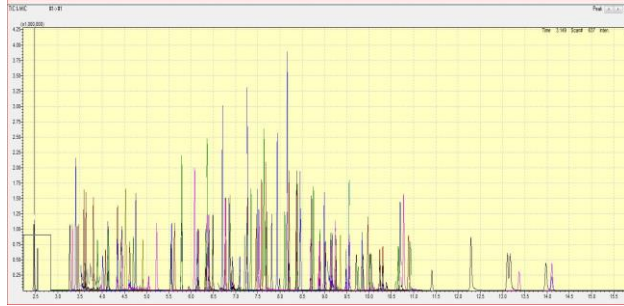


Figure 5: Mid-point standard MRM chromatogram from the 50ug/L calibration standard.

Method Detection Limit (MDL)

An instrument detection limit (IDL) study was made using eight replicate injections at 1.0, 2.0 and 5.0 ppb standards but with concentrations divided by 1000 to approximate MDLs for 1000 ml samples extracted and concentrated to 1 ml.

These estimated MDL results were compared to Method 608 detection limits and are shown in Table 5.

Table 5: Estimated MDL compared to method 608 MDL

Component	Estimated MDL (assumes 1000ml/1ml) µg/L			Method 608 MDL (µg/L)
	1 ppb standard	2 ppb standard	5 ppb standard	
Alpha-BHC	0.0002	0.0005	0.0004	0.003
Gamma-BHC (Lindane)	0.0003	0.0005	0.0004	0.004
Beta-BHC	0.0002	0.0004	0.0005	0.006
Delta- BHC	0.0003	0.0004	0.0007	0.009
Heptachlor	0.0003	0.0004	0.0007	0.003
Aldrin	0.0004	0.0007	0.001	0.004
Heptachlor Epoxide (isomer B)	0.0004	0.0007	0.0014	0.083
Trans-Chlordane	0.0002	0.0007	0.0011	0.014
Cis-Chlordane		0.0009	0.0016	0.014
Endosulfan I	0.0003	0.0006	0.0013	0.014
4,4'-DDE	0.0003	0.0003	0.0005	0.004
Dieldrin		0.0009	0.0022	0.002
Endrin		0.0008	0.0012	0.006
4,4'-DDD	0.0002	0.0003	0.0004	0.011
Endosulfan II		0.0009	0.0013	0.004
Endrin Aldehyde			0.0026	0.023
4,4'-DDT	0.0001	0.0003	0.0004	0.012
Endosulfan Sulfate	0.0002	0.0004	0.0005	0.066
Methoxychlor	0.0002	0.0004	0.0007	
Endrin Ketone			0.0014	
2-Chlorobiphenyl (#1)	0.0002	0.0004	0.0005	0.065*
2,3-Dichlorobiphenyl (#5)		0.0004	0.0004	
2,2',5-Trichlorobiphenyl (#18)		0.0003	0.0006	
2,2',5,5'-Tetrachlorobiphenyl (#52)	0.0002	0.0003	0.0004	
2,2',3,5'-Tetrachlorobiphenyl (#44)	0.0002	0.0002	0.0006	
2,3',4,4'-Tetrachlorobiphenyl (#66)	0.0002	0.0003	0.0004	
2,2',4,5,5'-Petachlorobiphenyl (#101)	0.0003	0.0004	0.0008	
2,2',3,4,5'-Pentachlorobiphenyl (#87)	0.0003	0.0004	0.0007	
2,3,3',4',6-Pentachlorobiphenyl (#110)	0.0003	0.0004	0.0008	
2,2',3,5,5',6-Hexachlorobiphenyl (#151)	0.0003	0.0004	0.0008	
2,2',4,4',5,5'-Hexachlorobiphenyl (#153)	0.0005	0.0002	0.0006	
2,2',3,4,5,5'-Hexachlorobiphenyl (#141)	0.0006	0.0004	0.0006	
2,2',3,4,4',5'-Hexachlorobiphenyl (#138)		0.0003	0.0006	

2,2',3,4',5,5',6-Heptachlorobiphenyl (#187)		0.0004	0.0009	
2,2'3,4,4',5',6- Heptachlorobiphenyl (#183)	0.0002	0.0003	0.0008	
2,2',3,4,4',5,5'-Heptachlorobiphenyl (#180)	0.0003	0.0003	0.0005	
2,2'3,3'4,4'5- Heptachlorobiphenyl (#170)	0.0001	0.0001	0.0004	
2,2'3,3'4,4',5,5',6-Nonachlorobiphenyl (#206)	0.0004	0.0003	0.0004	

*MDL given in Method 608 for Aroclor (PCB-1242)

Precision and Accuracy

Eight replicates of 10 ppb and 20 ppb were made to determine precision and accuracy. Table 6 lists the

results of the precision and accuracy study, reporting the % recovery and the %RSD for all compounds at both concentrations.

Table 6: Precision and accuracy for pesticides and PCB congeners

Component	Precision and Accuracy			
	10 ppb Standard		20 ppb standard	
	% REC	%RSD	%REC	%RSD
Alpha-BHC	96	2.3	87	2.7
Gamma-BHC (Lindane)	102	3.7	94	2.0
Beta-BHC	97	1.9	89	1.5
Delta- BHC	99	2.1	92	2.3
Heptachlor	107	4.8	104	2.0
Aldrin	114	6.0	110	1.6
Heptachlor Epoxide (isomer B)	122	7.1	118	3.7
Trans-Chlordane	108	4.8	101	5.2
Cis-Chlordane	128	5.4	124	4.8
Endosulfan I	113	13.0	112	2.9
4,4'-DDE	105	1.9	96	2.2
Dieldrin	110	13.3	113	5.3
Endrin	127	10.0	124	4.7
4,4'-DDD	102	2.3	99	1.9
Endosulfan II	129	10.3	131	5.4
Endrin Aldehyde	124	16.7	134	5.8
4,4'-DDT	119	1.9	115	1.7
Endosulfan Sulfate	116	2.2	115	1.6
Methoxychlor	126	2.7	122	1.8
Endrin Ketone	90	14.5	107	8.8
2-Chlorobiphenyl (#1)	96	1.8	86	3.1
2,3-Dichlorobiphenyl (#5)	97	1.9	87	1.3
2,2',5-Trichlorobiphenyl (#18)	97	1.2	87	1.2
2,4',5-Trichlorobiphenyl (#31)	98	1.7	88	1.3
2,2',5,5'-Tetrachlorobiphenyl (#52)	97	2.2	87	2.6
2,2'3,5'-Tetrachlorobiphenyl (#44)	101	3.1	90	2.0
2,3'4,4'-Tetrachlorobiphenyl (#66)	99	1.7	90	1.9
2,2',4,5,5'-Petachlorobiphenyl (#101)	102	2.6	94	2.4
2,2',3,4,5'-Pentachlorobiphenyl (#87)	99	2.5	89	3.0
2,3,3'4',6-Pentachlorobiphenyl (#110)	96	1.9	88	1.8
2,2',3,5,5',6-Hexachlorobiphenyl (#151)	106	3.2	97	3.6
2,2',4,4',5,5'-Hexachlorobiphenyl (#153)	106	2.9	96	2.6
2,2',3,4,5,5'-Hexachlorobiphenyl (#141)	104	2.1	97	1.3
2,2',3,4,4',5'-Hexachlorobiphenyl (#138)	111	3.3	105	1.3
2,2',3,4',5,5',6-Heptachlorobiphenyl (#187)	109	4.8	103	2.1
2,2'3,4,4',5',6- Heptachlorobiphenyl (#183)	110	3.1	102	2.7
2,2',3,4,4',5,5'-Heptachlorobiphenyl (#180)	102	2.9	94	1.8
2,2'3,3'4,4'5- Heptachlorobiphenyl (#170)	106	1.4	98	1.5
2,2'3,3'4,4',5,5',6-Nonachlorobiphenyl (#206)	101	1.7	95	1.5

Internal standard and surrogate stability

Five internal standards were used for calibration and four surrogate standards to measure recovery. Table 7 lists the components. Figure 6 and Figure 7 plot the internal standard area and the surrogate

standard recovery, respectively. The small variance (< 6 %RSD for all compounds) in the data demonstrates the long-term stability of the instrumental method.

Table 7: Internal and surrogate standards

IS 1	2-Fluorophenol
IS 2	Nitrobenzene-d5
IS 3	p-Terphenyl-d14(IS)
IS 4	Decachlorobiphenyl (BZ #209)
IS 5	Decafluorobiphenyl
SURR 1	Pentafluorophenol
SURR 2	2,4,5,6-tetrachloro-m-Xylene
SURR 3	4,4'-Dibromooctafluorobiphenyl
SURR 4	4,4'-Dibromobiphenyl(SURR)

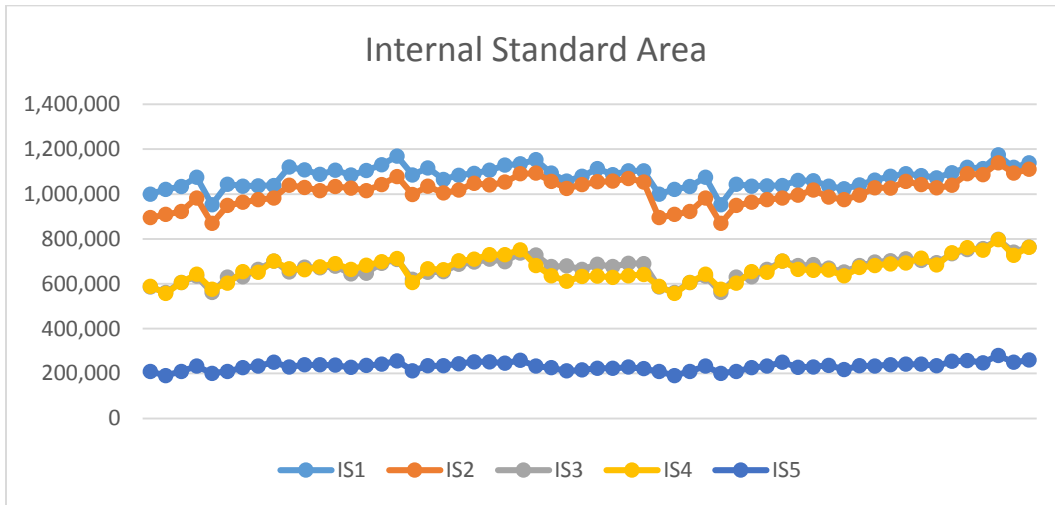


Figure 6: Internal standard area

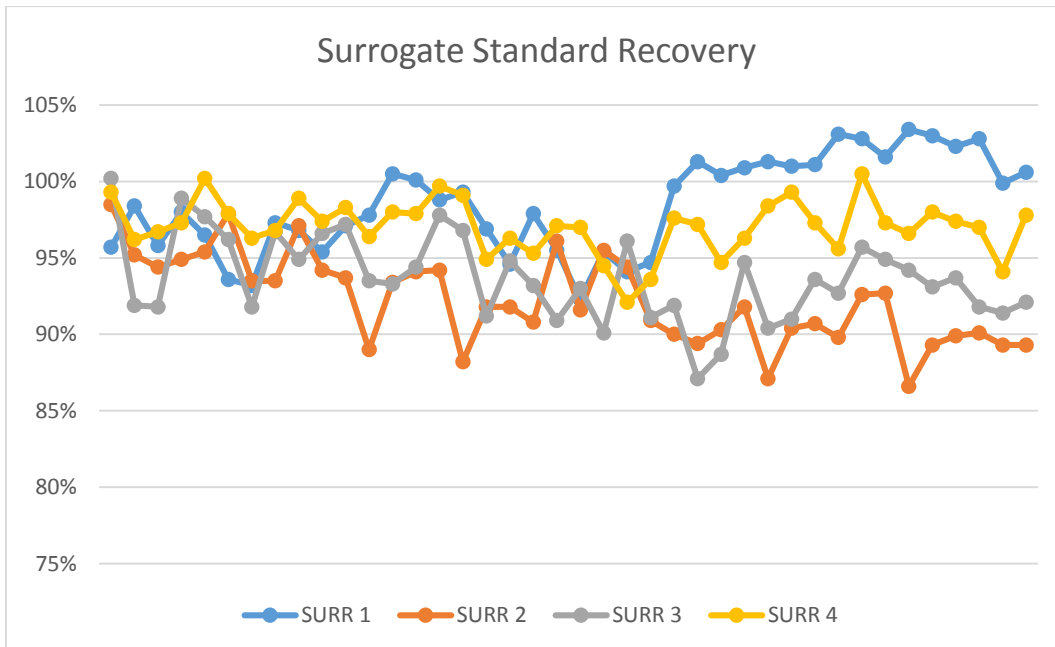


Figure 7: Surrogate standard recovery

■ Conclusion

Triple quadrupole GCMS analysis simplifies detection and quantitation of pesticides and PCBs. Detection limits are equal to or better than Method 608 detection limits. Triple quadrupole GCMS does not suffer from interferences nor does it require dual columns to confirm the identity of peaks. PCB analysis by Method 608 is difficult because the Aroclor pattern changes with weathering often resulting in samples containing PCBs being reported as not detected.

Using a triple quadrupole GCMS, such as the Shimadzu GCMS-TQ8040, for pesticides and PCB analysis is a viable alternative to EPA Method 608. This paper evaluated standards only. Our evaluation indicates that triple quadrupole GCMS is a suitable alternative to pesticide and PCB analysis by GC-ECD.

■ References

1. Technical Report C146-E230, Analysis of Pesticides in Food Matrix using QuEChERS by Triple Quadrupole GC/MS/MS and LC/MS/MS, Shimadzu Corporation, Japan, June 2013
2. US EPA Method 608, Organochlorine pesticides and PCBs, CFR40 Part 136 Appendix A
3. Technical Guide, Analysis of Halogenated Environmental Pollutants Using Electron Capture Detection, Restek Lit # EVTG1648-UNV, 2014
4. Knox, Dunning, Johnson, Spohn; Coelution of Contaminant Drivers at Cleanup Sites and the role of Consilience; Pacific Groundwater Group, Seattle WA and Analytical Resources Inc., Tukwila WA; Poster SETAC_November 2014
5. James J McAteer, Jr., and Erin Carroll Hughes; Bias in Organochlorine Pesticide Data, Comparison of Analysis by GC/ECD and HRGC/MSMS; NEMC 2014
6. <http://www3.epa.gov/epawaste/hazard/tsd/pcbs/pubs/congeners.htm>, accessed December 14, 2015
7. Wisckaemper, Biliveau, and Henderson; U.S. EPA Region 4 Technical Services Section Issue Paper for Polychlorinated Biphenyl Characterization at Region 4 Superfund and RCRA Sites; Groundwater Issue; 2/28/2013



SHIMADZU Corporation

www.shimadzu.com/an/

SHIMADZU SCIENTIFIC INSTRUMENTS

7102 Riverwood Drive, Columbia, MD 21046, USA

Phone: 800-477-1227/410-381-1227, Fax: 410-381-1222

URL: www.ssi.shimadzu.com

First Edition: January 2016

For Research Use Only. Not for use in diagnostic procedures.

The contents of this publication are provided to you "as is" without warranty of any kind, and are subject to change without notice.

Shimadzu does not assume any responsibility or liability for any damage, whether direct or indirect, relating to the use of this publication.