

Fast GC

Increase GC Speed Without Sacrificing Resolution



- Increase Productivity
- Utilize Resources More Effectively
- Achieve Quicker Turn-Around Times
- Analyze More Samples

Overview

Shorter analysis times allow increased sample throughput, which translates to the completion of more runs per shift. However, any decrease in analysis time must not diminish the resolution necessary to adequately resolve peaks of interest, or to identify specific elution patterns. The information presented in this brochure will show how to apply the Principles of Fast GC to increase GC speed without sacrificing resolution for any application in any industry.

The Six Principles of Fast GC

Simply stated, Fast GC is the manipulation of a number of parameters to provide faster analysis times while maintaining resolution. Analysis times are decreased by using:

1. Short columns
2. Fast oven temperature ramp rates
3. High carrier gas linear velocities

The loss in resolution caused by Principles 1–3 is offset by using:

4. Narrow I.D. columns
5. Hydrogen carrier gas
6. Low film thickness

Many of these parameters are related to each other. Changing just one may produce a shorter analysis, but may result in a loss in quality. Therefore, all parameters must be evaluated to make sure they are set correctly. The more Principles that are applied, the greater the benefit!

Why Do Fast GC?

Time and money! Fast GC yields faster analysis times than conventional GC, often three to ten times faster. The benefits are that:

- Costs can be decreased if fewer analysts and/or instruments are needed
- Revenue can be increased if more samples are analyzed
- It can be applied to any application with no sacrifice in quality
- It typically does not require any additional equipment

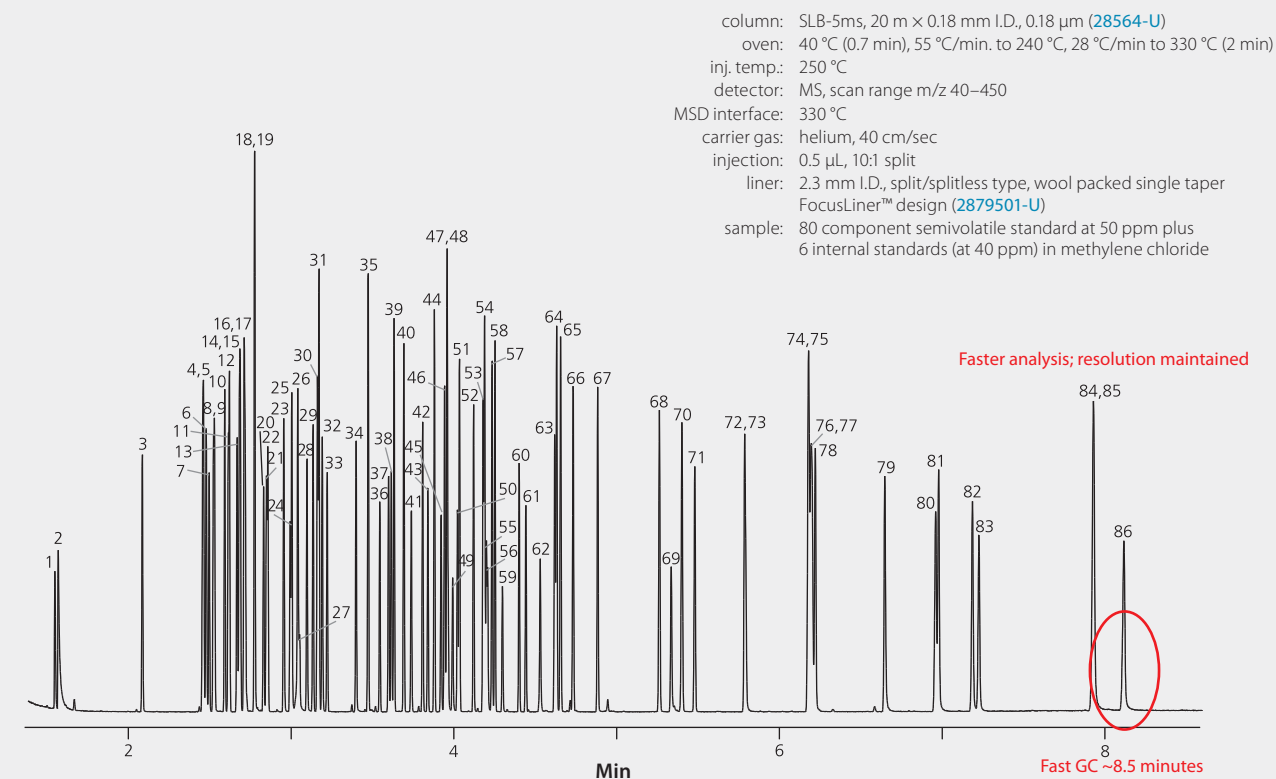
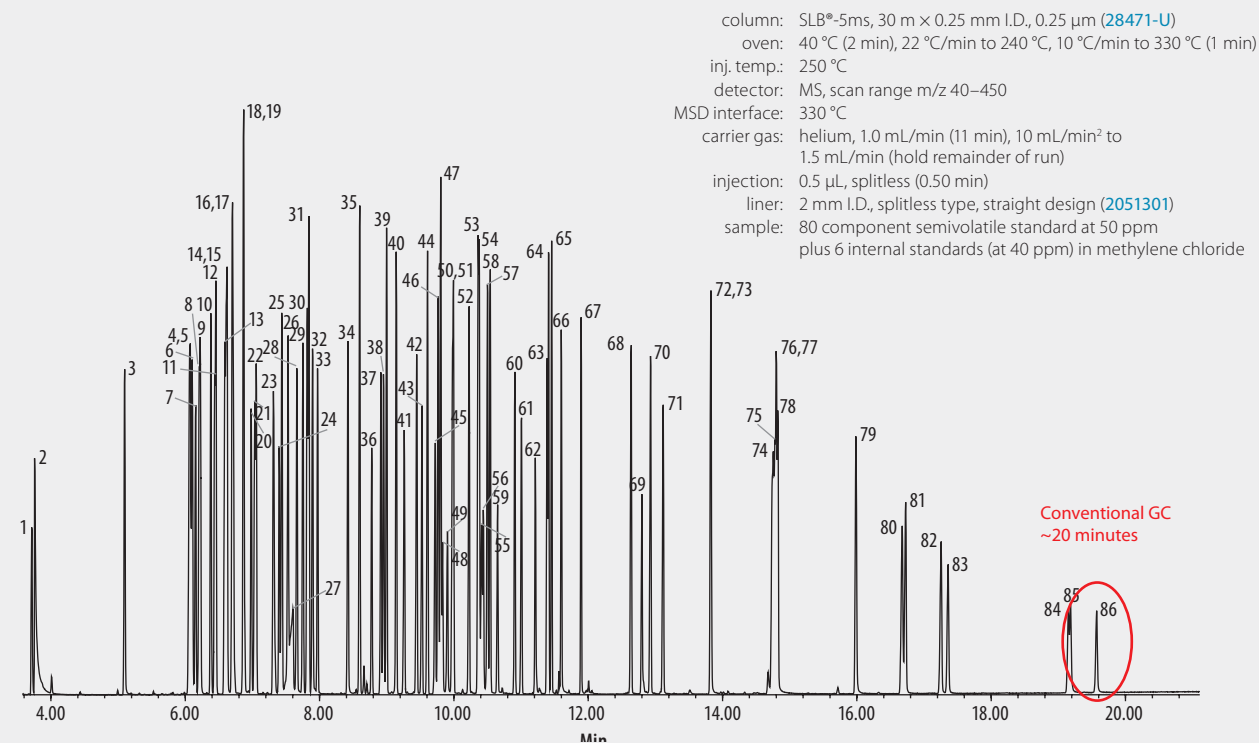
To highlight why Fast GC should be considered, **Figure 1** directly compares conventional GC to Fast GC. The example shown is the GC/MS analysis of semivolatiles, an application routinely performed in environmental laboratories.

The conventional GC method requires 20 min for this analysis, whereas the same resolution can be achieved in just 8.5 min after applying the Principles of Fast GC. Equally important is that this increase in sample throughput does not require any increase in staff or equipment.

Peak IDs for Figure 1

1. <i>N</i> -Nitrosodimethylamine	23. Isophorone	45. 3-Nitroaniline	67. Di- <i>n</i> -butyl phthalate
2. Pyridine	24. 2-Nitrophenol	46. Acenaphthene- <i>d</i> ₁₀ (I.S.)	68. Fluoranthene
3. 2-Fluorophenol (surr.)	25. 2,4-Dimethylphenol	47. Acenaphthene	69. Benzidine
4. Phenol- <i>d</i> ₆ (surr.)	26. Bis(2-chloroethoxy)methane	48. 2,4-Dinitrophenol	70. Pyrene
5. Phenol	27. Benzoic acid	49. 4-Nitrophenol	71. Terphenyl- <i>d</i> ₁₄ (surr.)
6. Aniline	28. 2,4-Dichlorophenol	50. Dibenzofuran	72. 3,3'-Dimethylbenzidine
7. Bis(2-chloroethyl)ether	29. 1,2,4-Trichlorobenzene	51. 2,4-Dinitrotoluene	73. Butylbenzyl phthalate
8. 2-Chlorophenol- <i>d</i> ₃ (surr.)	30. Naphthalene- <i>d</i> ₈ (I.S.)	52. Diethyl phthalate	74. 3,3'-Dichlorobenzidine
9. 2-Chlorophenol	31. Naphthalene	53. 4-Chlorophenyl phenyl ether	75. Benzo(a)anthracene
10. 1,3-Dichlorobenzene	32. 4-Chloroaniline	54. Fluorene	76. Bis(2-ethylhexyl)phthalate
11. 1,4-Dichlorobenzene- <i>d</i> ₄ (I.S.)	33. Hexachlorobutadiene	55. 4-Nitroaniline	77. Chrysene- <i>d</i> ₁₂ (I.S.)
12. 1,4-Dichlorobenzene	34. 4-Chloro-3-methylphenol	56. 2-Methyl-4,6-dinitrophenol	78. Chrysene
13. Benzyl alcohol	35. 2-Methylnaphthalene	57. <i>N</i> -nitrosodiphenylamine	79. Di- <i>n</i> -octyl phthalate
14. 1,2-Dichlorobenzene- <i>d</i> ₄ (surr.)	36. Hexachlorocyclopentadiene	58. Azobenzene	80. Benzo(b)fluoranthene
15. 1,2-Dichlorobenzene	37. 2,4,6-Trichlorophenol	59. 2,4,6-Tribromophenol (surr.)	81. Benzo(k)fluoranthene
16. 2-Methylphenol	38. 2,4,5-Trichlorophenol	60. 4-Bromophenyl phenyl ether	82. Benzo(a)pyrene
17. Bis(2-chloroisopropyl)ether	39. 2-Fluorobiphenyl (surr.)	61. Hexachlorobenzene	83. Perylene- <i>d</i> ₁₂ (I.S.)
18. <i>N</i> -Nitroso-di- <i>n</i> -propylamine	40. 2-Chloronaphthalene	62. Pentachlorophenol	84. Indeno(1,2,3- <i>cd</i>)pyrene
19. 4-Methylphenol	41. 2-Nitroaniline	63. Phenanthrene- <i>d</i> ₁₀ (I.S.)	85. Dibenzo(a,h)anthracene
20. Hexachloroethane	42. Dimethyl phthalate	64. Phenanthrene	86. Benzo(g,h,i)perylene
21. Nitrobenzene- <i>d</i> ₅ (surr.)	43. 2,6-Dinitrotoluene	65. Anthracene	
22. Nitrobenzene	44. Acenaphthylene	66. Carbazole	

Figure 1. Conventional GC vs Fast GC Analysis



Theoretical Discussion

This section defines how Fast GC works through a theoretical discussion.

Principles 1–3 (Decrease Analysis Time)

How long analytes are retained in a column dictates the overall analysis time. The retention time (t_R) of an analyte is a function of column length (L), retention factor (k), and carrier gas linear velocity (μ). The equation shown in **Figure 2** defines those relationships.

Figure 2. Retention Time Equation

$$t_R = \frac{L(k+1)}{\mu}$$

The correct units for each term are not needed for this discussion. Rather, the relationships (cause and effect) are important. There are three options for reducing t_R :

1. Decrease L: Use a shorter column
2. Decrease k: Increase oven temperature and/or ramp rate to reduce analyte partitioning into the stationary phase
3. Increase μ : Increase the carrier gas linear velocity to move analytes through the column quicker

These are Principles 1–3. They accomplish shortening analysis time, but sacrifice resolution in doing so. Principles 4–6 focus on gaining back the resolution.

Resolution

Before discussing Principles 4–6 (increase resolution), the relationships between resolution and plate height needs to be understood. The resolution equation shown in **Figure 3** reveals that resolution (R_s) is the result of selectivity times efficiency times capacity.

Figure 3. The Resolution Equation

$$R_s = \text{Selectivity} * \text{Efficiency} * \text{Capacity}$$

$$R_s = ((\alpha-1)/\alpha) * (N^{1/2}/4) * (k/(1+k))$$

The equation in **Figure 4** shows that efficiency (N, expressed as plates) is inversely related to plate height (H).

Figure 4. Relationship of Efficiency and Plate Height

$$N = L/H$$

Working through both equations reveals that a decrease in plate height (H) will increase efficiency (N) which in turn will increase resolution (R_s). Therefore, Principles 4–6 deal with decreasing H as the means to increase resolution.

Principles 4–6 (Increase Resolution)

How can plate height (H) be decreased? The Golay equation shown in **Figure 5**, is the classic van Deemter equation minus the A term, which does not apply to open tubes.

Figure 5. Golay Equation

$$H = \frac{2D_m}{\mu} + \left[\frac{(1+6k+11k^2)r^2}{24(1+k)^2D_m} \right] * \mu + \left[\frac{k^3r^2}{6(1+k)^2k^2D_s} \right] * \mu$$

This equation is useful because it describes H, and its relationships to several terms. The correct units for each term are not needed for this discussion. Rather, the relationships (cause and effect) are important. There are three options for decreasing H:

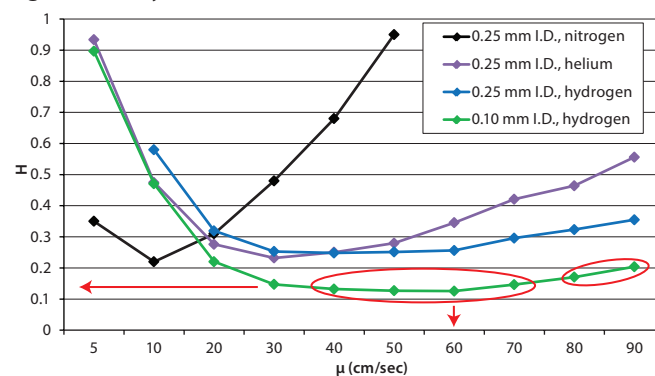
4. Decrease r (radius): Use a column with a narrower I.D.
5. Increase D_m (mobile phase diffusivity): Use hydrogen instead of helium as the carrier gas
6. Increase D_s (stationary phase diffusivity): Use a column with a thinner film thickness

These are Principles 4–6. They accomplish gaining back the resolution lost when Principles 1–3 were applied.

Narrow I.D. and Hydrogen

The combined effect of a narrow I.D. column (Principle 4) and hydrogen carrier gas (Principle 5) is very powerful. The Golay plots shown in **Figure 6** represent various combinations of column I.D. and carrier gas. The X-axis shows linear velocity (μ), and the Y-axis shows plate height (H). The phrase optimal linear velocity (μ_{opt}) is used to define the linear velocity value when the Golay plot is at its lowest point. Data for a 0.10 mm I.D. column with helium carrier gas is not included due to the high backpressure generated by this combination.

Figure 6. Golay Plots



Higher μ values result in shorter analysis times, whereas lower H values result in greater efficiency and resolution. A 0.10 mm I.D. column used with hydrogen provides:

- A high μ_{opt}
- A low H value
- A flat Golay relationship, allowing the use of $\mu > \mu_{opt}$ without a significant increase in H
- The ability to use $\mu = 90$ cm/sec and still achieve lower H than other combinations

Practical Considerations Tutorial

There are a few practical considerations to be aware of.

1. **Oven Ramp Rates.** Fast oven temperature ramp rates (Principle 2) can be used to decrease analysis time. However, it is important to stay within the ramp rate limits of the GC for the temperature ranges it will be operated at. Programming a ramp rate faster than the GC can maintain may result in variations from run to run. Therefore, do not set a ramp rate faster than the instrument can manage. If it is desired to use a faster ramp rate, decreasing the internal oven volume with an oven insert is an inexpensive and simple way to increase ramp rate capability.
2. **Sample Capacity.** Narrow I.D. columns (Principle 4) have lower sample capacity compared to conventional GC column dimensions. To prevent peak shapes from being distorted, a smaller amount of sample must be introduced. Therefore, use high split ratios (100:1 to 400:1) to prevent column overload. Note that sensitivity will not suffer because narrow I.D. columns generate peaks with greater signal-to-noise ratios.
3. **Acquisition Rates.** Compared to conventional GC, Fast GC will produce more frequent and much narrower peaks, which the detector must handle. Therefore, verify the detector can obtain sufficient data points per peak to ensure proper peak quantitation. Most detectors in service should in fact be compatible with Fast GC.
4. **GC/MS.** The preferred carrier gas for Fast GC is hydrogen (Principle 5). However, many mass spectrometer detectors (MSDs) will not work properly with hydrogen as the carrier gas. Therefore, when using an MSD that is not compatible with hydrogen carrier gas, this Principle cannot be applied. However, the other five Principles can and should be applied.

In this section, seven chromatograms show how performance changes as a conventional GC method is converted to a Fast GC method. **Table 1** lists conditions other than those listed with each figure, and **Table 2** lists peak IDs.

Table 1. Conditions for Figures 7–13

inj. temp.:	250 °C
detector:	FID, 325 °C
liner:	2 mm I.D., split/splitless type, wool packed single taper FocusLiner™ design
sample:	16 PAHs, each at 100 µg/mL in methylene chloride

Table 2. Peak IDs for Figures 7–13

1. Naphthalene	9. Benzo[a]anthracene
2. Acenaphthylene	10. Chrysene
3. Acenaphthene	11. Benzo[b]fluoranthene
4. Fluorene	12. Benzo[k]fluoranthene
5. Phenanthrene	13. Benzo[a]pyrene
6. Anthracene	14. Indeno[1,2,3-cd]pyrene
7. Fluoranthene	15. Dibenzo[a,h]anthracene
8. Pyrene	16. Benzo[g,h,i]perylene

Table 3 displays which figures correlate to each Principle. Note that some Principles were applied more than once.

Table 3. Correlation of Figures to Principles

Principle	Description	Figure
1	Use shorter column	8,11
2	Use higher temp and/or faster ramp rate	13
3	Use faster linear velocity	9,12
4	Use narrower I.D.	10
5	Use hydrogen carrier gas	9
6	Use thinner film	10

Figure 7 is a conventional GC analysis of 16 polycyclic aromatic hydrocarbons (PAHs) using a 30 m × 0.25 mm I.D. column and flame ionization detector (FID). The oven temperature ramp rate of 20 °C/min is the maximum single rate possible over the 70–325 °C temperature range. The difficult separations are peaks 5/6, 9/10, 11/12, and 14/15. Resolution values of 1.7, 1.1, and 0.6 are reported for the first three pairs. A value of 1.5 or greater signifies baseline resolution. The last pair shows no separation. To achieve better resolution for all pairs, a lower initial oven temperature could be used. However, this would extend the analysis time even longer than the 19 minutes shown.

Figure 7. Initial (Conventional GC)

column: SLB-5ms, 30 m × 0.25 mm I.D., 0.25 μm
 oven: 70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
 carrier gas: helium at 25 cm/sec
 injection: 0.5 μL, 10:1 split

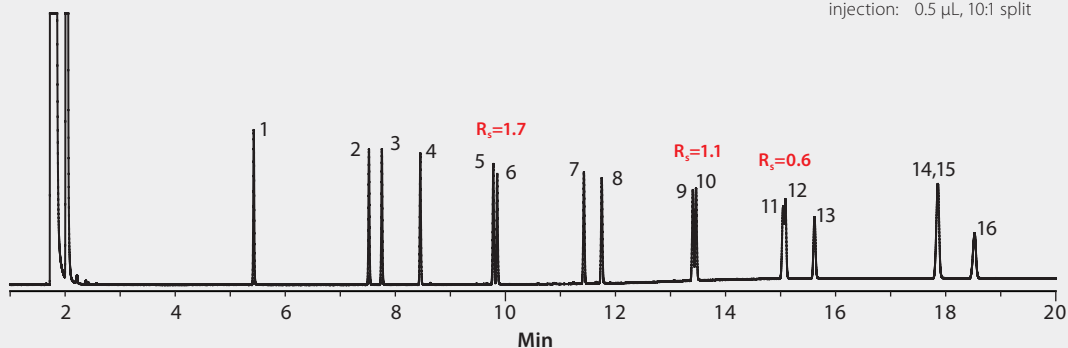


Figure 8 shows the same application with a shorter column. Analysis time is decreased, and resolution values are lower. This is a shorter run (desired), but the resolution is unacceptable (not desired).

Figure 8. Decrease Column Length

column: SLB-5ms, 15 m × 0.25 mm I.D., 0.25 μm
 oven: 70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
 carrier gas: helium at 25 cm/sec
 injection: 0.5 μL, 10:1 split

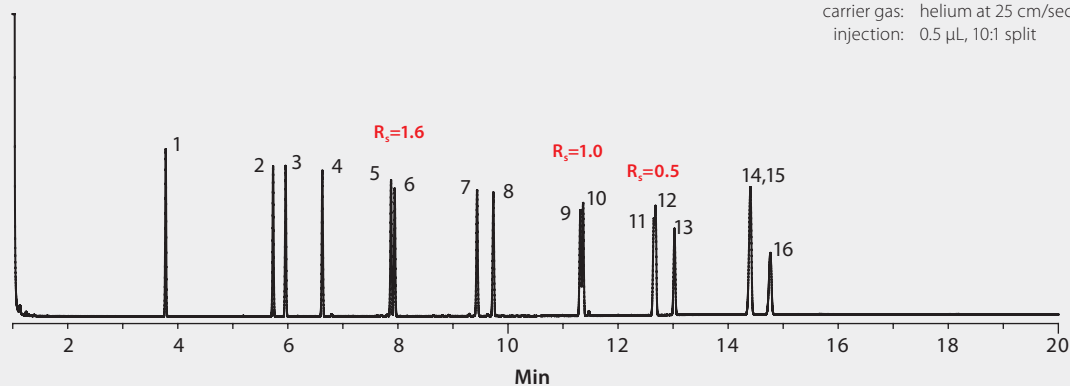
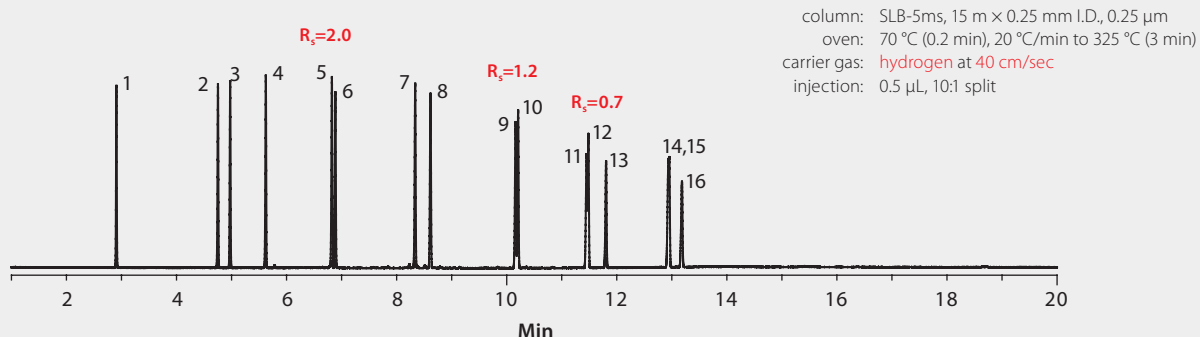


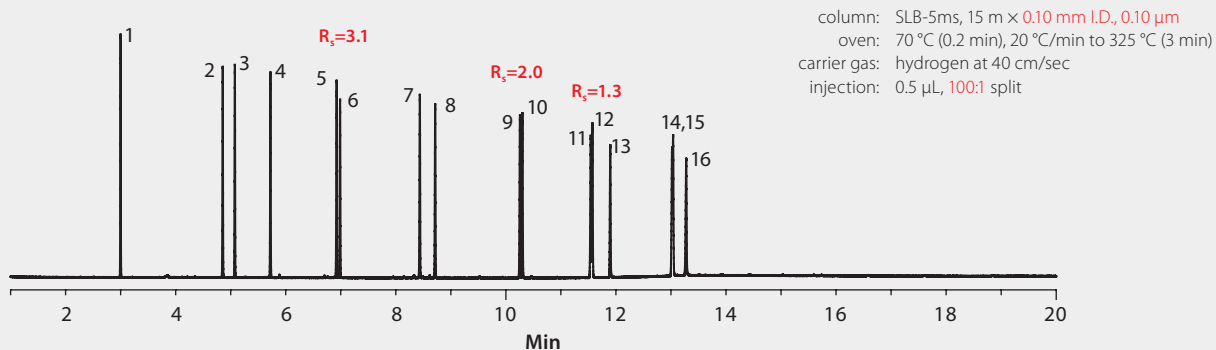
Figure 9 shows what happens when carrier gas is changed from helium at 25 cm/sec to hydrogen at 40 cm/sec. Analysis time is decreased, and the resolution values are higher. Why did resolution get better? Hydrogen at its optimal linear velocity with a 0.25 mm I.D. column ($\mu_{opt} = 40$ cm/sec) has a lower plate height (H) value than helium at its optimal linear velocity with a 0.25 mm I.D. column ($\mu_{opt} = 25$ cm/sec).

Figure 9. Switch to Hydrogen Carrier Gas



Principle 4 states that decreasing column I.D. will decrease plate height (H), which increases efficiency (N) and subsequently resolution (R_s). Figure 10 shows the same application using a smaller I.D. column. The film thickness was also lowered to keep the same ratio of stationary phase film thickness to column cross-sectional area. Additionally, the split ratio was increased to minimize the risk of column overload. Observe that analysis time is unchanged, and that resolution values are higher.

Figure 10. Decrease Column I.D.



Decreasing column length again results in Figure 11. As expected, analysis time decreases. Resolution values are lower, except for the fourth pair. How is this possible? This pair now elutes during the oven temperature ramp and not the final isothermal portion of the run, resulting in sharper peak shapes. Generating sharper peak shapes can also be used to increase resolution.

Figure 11. Decrease Column Length

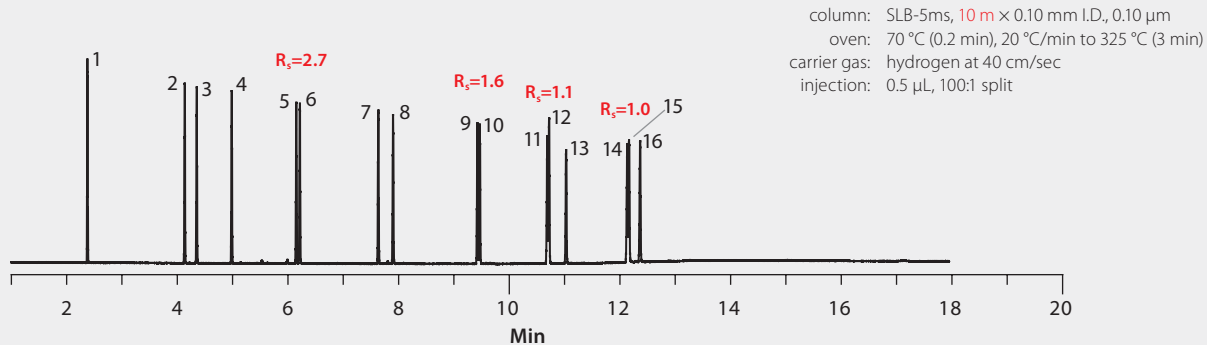


Figure 12 is the result after linear velocity is increased. As expected, analysis time decreases. Why are the resolution values higher? Because the linear velocity used in Figures 10 and 11 was sub-optimal. How did that happen?

1. In Figure 9, linear velocity was increased from 25 cm/sec to 40 cm/sec when the carrier gas was changed from helium to hydrogen. This was done to maintain optimal linear velocity (μ_{opt}).
2. In Figure 10, column I.D. was changed from 0.25 mm to 0.10 mm without adjusting linear velocity. This is a common mistake. The Golay plots in Figure 6 show that μ_{opt} is 40 cm/sec for hydrogen with a 0.25 mm I.D. column and 60 cm/sec with a 0.10 mm I.D. column.

The error was corrected in Figure 12 when μ_{opt} was used. To achieve the best resolution, it is critical to operate at the optimal linear velocity for the combination of column I.D. and carrier gas being used.

Figure 12. Increase Linear Velocity

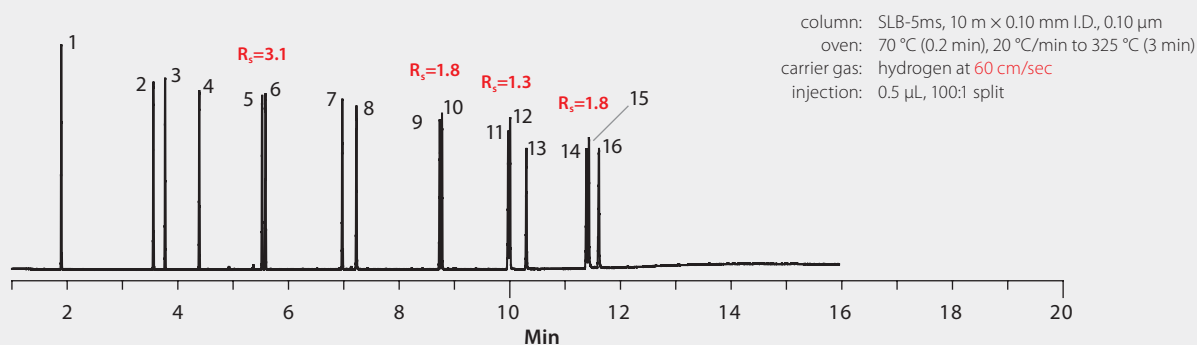
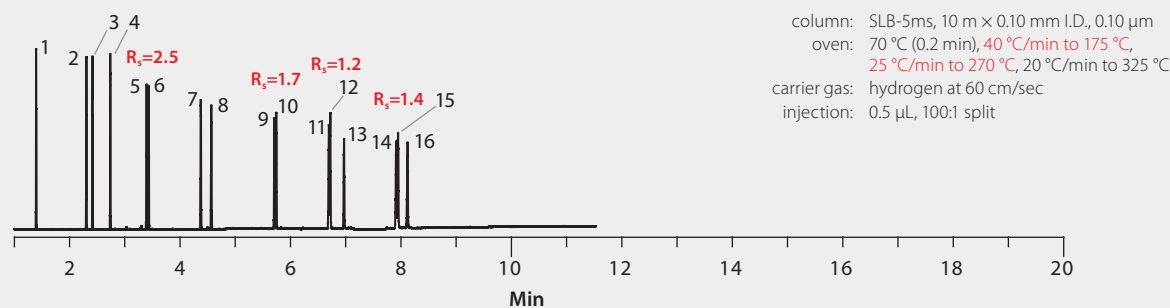


Figure 13 shows the result of using the maximum ramp rate possible over several temperature ranges. These maximum rates are typically published in the instrument manual. As expected, analysis time decreased, and resolution values are lower. Note that the resolution values did not suffer significantly. Why not? The discussion of Figure 11 mentioned that sharper peak shapes and better resolution are achieved if a pair elutes during the oven temperature ramp and not the final isothermal portion of the run. Sharper peak shapes are also obtained with a steeper temperature ramp. While the faster ramp will cause lower resolution values, the effect is minimized due to the sharper peak shapes that are produced.

Figure 13. Increase Ramp Rate

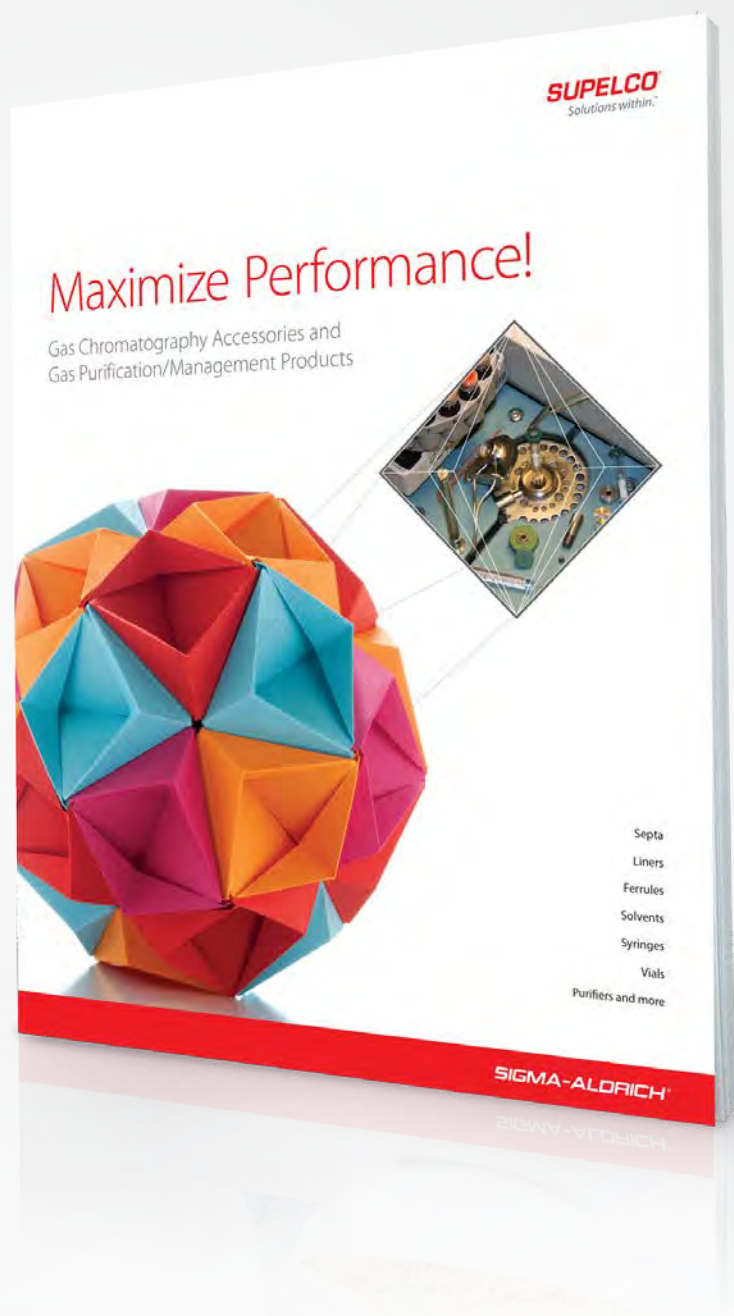


Converting this PAH method from conventional GC (Figure 7) to Fast GC (Figure 13) resulted in a 57% decrease in analysis time and vastly improved resolution. The greatest benefits can be achieved when all six principles are applied.

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Fast GC Applications

The 22 chromatograms listed in **Table 4** are included in this section. The greatest benefits can be achieved when all six principles are applied. However, this is not always possible. When helium is used instead of hydrogen as the carrier gas (such as when using GC/MS), only five principles can be applied. The carrier gas used is clearly listed in the conditions for each chromatogram.

Table 4. List of Applications

Industry	Description	Page
Environmental		
	US EPA Method 624 Volatiles on SPB-624	12
	US EPA Method 8260 Volatiles on VOCOL	13
	US EPA Method 8270 Semivolatiles on SLB-5ms (0.18 μ m)	14
	US EPA Method 8270 Semivolatiles on SLB-5ms (0.36 μ m)	15
	US EPA Method 8081 Organochlorine Pesticides on SLB-5ms	16
	US EPA Method 8081 Organochlorine Pesticides on Equity-1701	16
	US EPA Method 8082 PCBs as Aroclors on SLB-5ms	17
	US EPA Method 8082 PCBs as Aroclors on Equity-1701	17
Petroleum/Chemical		
	Unleaded Gasoline on Equity-1	18
	Fuel Oil #2 on Equity-1	18
	Kerosene on SLB-5ms	19
	Aviation Gasoline on Equity-1	19
Food and Beverage		
	PUFA No. 1 Mix (Marine Source) FAMES on Omegawax	20
	PUFA No. 2 Mix (Animal Source) FAMES on Omegawax	20
	PUFA No. 3 Mix (Menhaden Oil) FAMES on Omegawax	21
	Amino Acids on SLB-5ms	21
Flavor and Fragrance/Cosmetic		
	Lemon Essential Oil on SLB-5ms	22
	Distilled Lime Essential Oil on Equity-1	22
	Sweet Orange Essential Oil on SLB-5ms	23
	Allergens in Commercial Perfume on SLB-5ms	23
Clinical		
	Bacterial Acid Methyl Esters (BAMES) on Equity-1	24
	FAMES in Plasma on SUPELCOWAX 10	24

Environmental Applications

Figure 14. US EPA Method 624 Volatiles on SPB-624

sample/matrix: each analyte at 50 ppb in 5 mL water
 purge trap: VOCARB® 3000 "K" (24940-U)
 purge: 40 mL/min at 25 °C for 11 min
 dry purge: 2 min
 desorption temp.: 210 °C for 2 min
 desorption flow: 150 mL/min
 bake: 260 °C for 10 min
 transfer line/valve temp.: 110 °C
 column: SPB-624, 20 m x 0.18 mm I.D., 1.0 µm (28662-U)
 oven: 40 °C (1 min), 11 °C/min to 125 °C,
 35 °C/min to 230 °C (2 min)
 inj.: 150 °C
 MSD interface: 200 °C
 scan range: m/z = 35-400
 carrier gas: helium, 1.5 mL/min
 injection: 100:1 split
 liner: 0.75 mm I.D. SPME

- | | |
|---|---|
| 1. Chloromethane | 20. Bromodichloromethane |
| 2. Vinyl chloride | 21. 2-Chloroethyl vinyl ether |
| 3. Bromomethane | 22. <i>cis</i> -1,3-Dichloropropene |
| 4. Chloroethane | 23. Toluene-d ₈ (surr.) |
| 5. Trichlorofluoromethane | 24. Toluene |
| 6. 1,1-Dichloroethene | 25. <i>trans</i> -1,3-Dichloropropene |
| 7. Methylene chloride | 26. 1,1,2-Trichloroethane |
| 8. <i>trans</i> -1,2-Dichloroethene | 27. Tetrachloroethene |
| 9. 1,1-Dichloroethane | 28. Dibromochloromethane |
| 10. Chloroform | 29. Chlorobenzene-d ₅ (I.S.) |
| 11. Dibromofluoromethane (surr.) | 30. Chlorobenzene |
| 12. 1,1,1-Trichloroethane | 31. Ethylbenzene |
| 13. Carbon tetrachloride | 32. Bromoform |
| 14. 1,2-Dichloroethane-d ₂ (surr.) | 33. 4-Bromofluorobenzene (surr.) |
| 15. Benzene | 34. 1,1,2,2-Tetrachloroethane |
| 16. 1,2-Dichloroethane | 35. 1,3-Dichlorobenzene |
| 17. Fluorobenzene (I.S.) | 36. 1,4-Dichlorobenzene-d ₂ (I.S.) |
| 18. Trichloroethene | 37. 1,4-Dichlorobenzene |
| 19. 1,2-Dichloropropane | 38. 1,2-Dichlorobenzene |

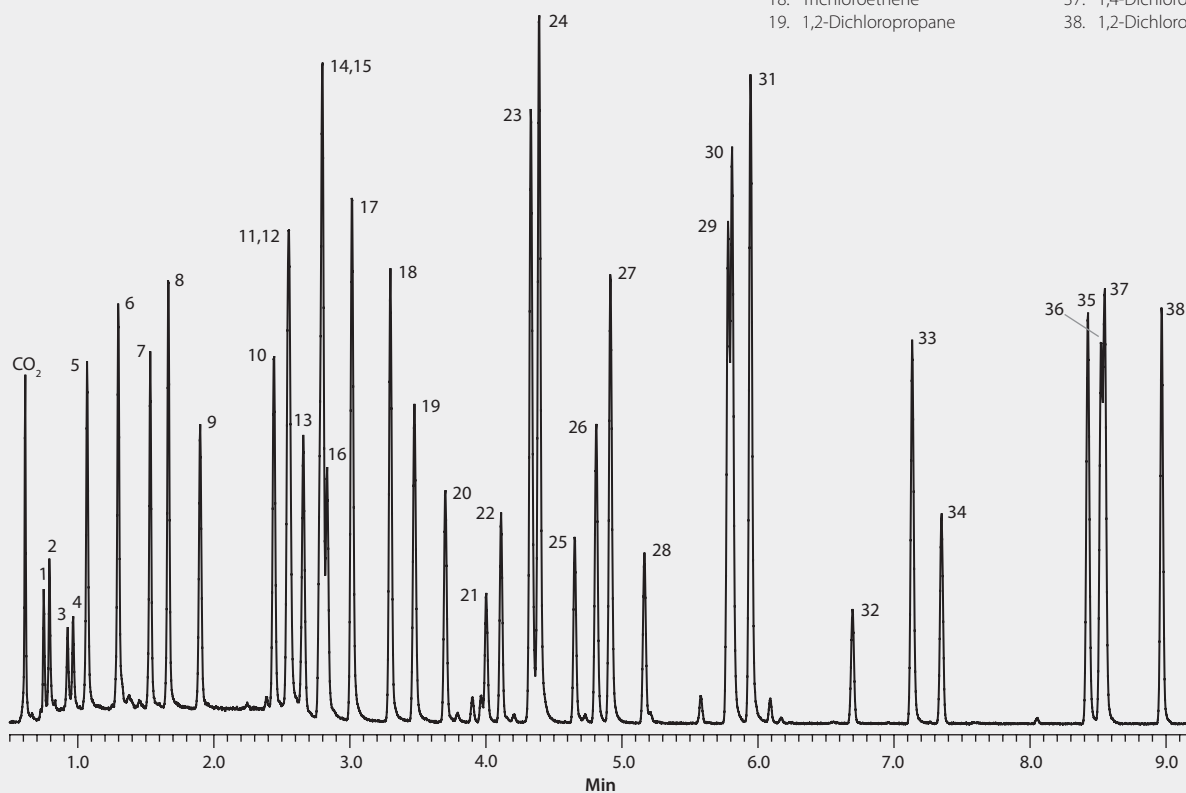


Figure 15. US EPA Method 8260 Volatiles on VOCOL

sample/matrix: each analyte at 50 ppb in 5 mL water
 purge trap: VOCARB 3000 "K" (24940-U)
 purge: 40 mL/min at 25 °C for 11 min
 dry purge: 1 min
 desorption temp.: 210 °C for 1 min
 desorption flow: 150 mL/min
 bake: 260 °C for 10 min
 transfer line/valve temp.: 110 °C
 column: VOCOL, 20 m x 0.18 mm I.D., 1.0 µm (28463-U)
 oven: 40 °C (0.8 min), 19 °C/min to 125 °C,
 32 °C/min to 220 °C (1 min)
 inj.: 150 °C
 MSD interface: 220 °C
 scan range: m/z = 35-400
 carrier gas: helium, 1.5 mL/min
 injection: 100:1 split
 liner: 0.75 mm I.D. SPME

- | | |
|--------------------------------------|---|
| 1. Dichlorofluoromethane | 12. 1,1-Dichloroethane |
| 2. Chloromethane | 13. 2-Butanone |
| 3. Vinyl chloride | 14. 2,2-Dichloropropane |
| 4. Bromomethane | 15. <i>cis</i> -1,2-Dichloroethene |
| 5. Chloroethane | 16. Chloroform |
| 6. Trichlorofluoromethane | 17. Bromochloromethane |
| 7. Acetone | 18. Dibromofluoromethane (surr.) |
| 8. 1,1-Dichloroethene | 19. 1,1,1-Trichloroethane |
| 9. Iodomethane | 20. 1,1-Dichloropropene |
| 10. Methylene chloride | 21. Carbon tetrachloride |
| 11. <i>trans</i> -1,2-Dichloroethene | 22. 1,2-Dichloroethane- <i>d</i> ₄ (surr.) |

- | | |
|---|---|
| 23. 1,2-Dichloroethane | 49. Bromoform |
| 24. Benzene | 50. <i>cis</i> -1,4-Dichloro-2-butene |
| 25. Fluorobenzene (I.S.) | 51. 1,1,2,2-Tetrachloroethane |
| 26. Trichloroethene | 52. 4-Bromofluorobenzene (surr.) |
| 27. 1,2-Dichloropropane | 53. 1,2,3-Trichloropropane |
| 28. Bromodichloromethane | 54. <i>n</i> -Propylbenzene |
| 29. Dibromomethane | 55. Bromobenzene |
| 30. 4-Methyl-2-pentanone | 56. <i>trans</i> -1,4-Dichloro-2-butene |
| 31. <i>cis</i> -1,3-Dichloropropene | 57. 1,3,5-Trimethylbenzene |
| 32. Toluene- <i>d</i> ₅ (surr.) | 58. <i>o</i> -Chlorotoluene |
| 33. Toluene | 59. <i>p</i> -Chlorotoluene |
| 34. <i>trans</i> -1,3-Dichloropropene | 60. <i>tert</i> -Butylbenzene |
| 35. 1,1,2-Trichloroethane | 61. 1,2,4-Trimethylbenzene |
| 36. 2-Hexanone | 62. Pentachloroethane |
| 37. 1,3-Dichloropropane | 63. <i>sec</i> -Butylbenzene |
| 38. Tetrachloroethene | 64. <i>p</i> -Isopropyltoluene |
| 39. Dibromochloromethane | 65. 1,3-Dichlorobenzene |
| 40. 1,2-Dibromomethane | 66. 1,4-Dichlorobenzene- <i>d</i> ₄ (I.S.) |
| 41. Chlorobenzene- <i>d</i> ₅ (I.S.) | 67. 1,4-Dichlorobenzene |
| 42. Chlorobenzene | 68. Butylbenzene |
| 43. Ethylbenzene | 69. 1,2-Dichlorobenzene |
| 44. 1,1,1,2-Tetrachloroethane | 70. 1,2-Dibromo-3-chloropropane |
| 45. <i>m</i> -Xylene & <i>p</i> -Xylene | 71. 1,2,4-Trichlorobenzene |
| 46. <i>o</i> -Xylene | 72. Hexachlorobutadiene |
| 47. Styrene | 73. Naphthalene |
| 48. Isopropylbenzene | 74. 1,2,3-Trichlorobenzene |

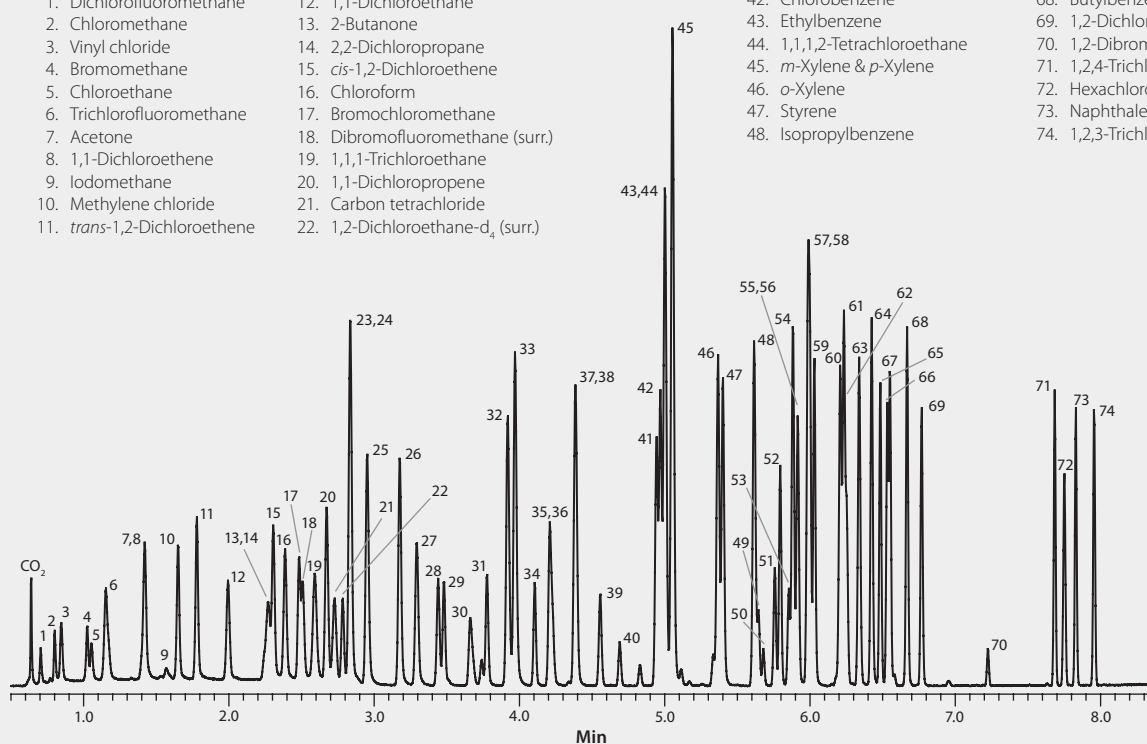


Figure 16. US EPA Method 8270 Semivolatiles on SLB-5ms (0.18 µm)

column: SLB-5ms, 20 m x 0.18 mm I.D., 0.18 µm (28564-U)
 oven: 40 °C (0.7 min), 55 °C/min to 240 °C, 28 °C/min to 330 °C (2 min)
 inj.: 250 °C
 MSD interface: 330 °C
 scan range: m/z 40-450
 carrier gas: helium, 40 cm/sec, constant
 injection: 0.5 µL, 10:1 split
 liner: 2 mm I.D., fast FocusLiner inlet liner with taper (2879501-U)
 sample: 80-component semivolatile standard at 50 ppm plus
 6 internal standards (at 40 ppm) in methylene chloride

- | | |
|--|---|
| 1. N-Nitrosodimethylamine | 15. 1,2-Dichlorobenzene |
| 2. Pyridine | 16. 2-Methylphenol |
| 3. 2-Fluorophenol (surr.) | 17. Bis(2-chloroisopropyl)ether |
| 4. Phenol-d ₆ (surr.) | 18. N-Nitroso-di-n-propylamine |
| 5. Phenol | 19. 4-Methylphenol |
| 6. Aniline | 20. Hexachloroethane |
| 7. Bis(2-chloroethyl)ether | 21. Nitrobenzene-d ₅ (surr.) |
| 8. 2-Chlorophenol-d ₄ (surr.) | 22. Nitrobenzene |
| 9. 2-Chlorophenol | 23. Isophorone |
| 10. 1,3-Dichlorobenzene | 24. 2-Nitrophenol |
| 11. 1,4-Dichlorobenzene | 25. 2,4-Dimethylphenol |
| 12. 1,4-Dichlorobenzene-d ₄ (I.S.) | 26. Bis(2-chloroethoxy)methane |
| 13. Benzyl alcohol | 27. Benzoic acid |
| 14. 1,2-Dichlorobenzene-d ₄ (surr.) | 28. 2,4-Dichlorophenol |

- | | |
|---|---|
| 29. 1,2,4-Trichlorobenzene | 58. Azobenzene |
| 30. Naphthalene-d ₈ (I.S.) | 59. 2,4,6-Tribromophenol (surr.) |
| 31. Naphthalene | 60. 4-Bromophenyl phenyl ether |
| 32. 4-Chloroaniline | 61. Hexachlorobenzene |
| 33. Hexachlorobutadiene | 62. Pentachlorophenol |
| 34. 4-Chloro-3-methylphenol | 63. Phenanthrene-d ₁₀ (I.S.) |
| 35. 2-Methylnaphthalene | 64. Phenanthrene |
| 36. Hexachlorocyclopentadiene | 65. Anthracene |
| 37. 2,4,6-Trichlorophenol | 66. Carbazole |
| 38. 2,4,5-Trichlorophenol | 67. Di-n-butyl phthalate |
| 39. 2-Fluorobiphenyl (surr.) | 68. Fluoranthene |
| 40. 2-Chloronaphthalene | 69. Benzidine |
| 41. 2-Nitroaniline | 70. Pyrene |
| 42. Dimethyl phthalate | 71. Terphenyl-d ₄ (surr.) |
| 43. 3-Nitroaniline | 72. 3,3'-Dimethylbenzidine |
| 44. Acenaphthylene | 73. Butylbenzyl phthalate |
| 45. 2,6-Dinitrotoluene | 74. 3,3'-Dichlorobenzidine |
| 46. Acenaphthene-d ₁₀ (I.S.) | 75. Bis(2-ethylhexyl)phthalate |
| 47. Acenaphthene | 76. Benzo(a)anthracene |
| 48. 2,4-Dinitrophenol | 77. Chrysene-d ₁₂ (I.S.) |
| 49. 4-Nitrophenol | 78. Chrysene |
| 50. 2,4-Dinitrotoluene | 79. Di-n-octyl phthalate |
| 51. Dibenzofuran | 80. Benzo(k)fluoranthene |
| 52. Diethyl phthalate | 81. Benzo(k)fluoranthene |
| 53. 4-Chlorophenyl phenyl ether | 82. Benzo(a)pyrene |
| 54. Fluorene | 83. Perylene-d ₁₂ (I.S.) |
| 55. 4-Nitroaniline | 84. Indeno(1,2,3-cd)pyrene |
| 56. 2-Methyl-4,6-dinitrophenol | 85. Dibenzo(a,h)anthracene |
| 57. N-Nitrosodiphenylamine | 86. Benzo(g,h,i)perylene |

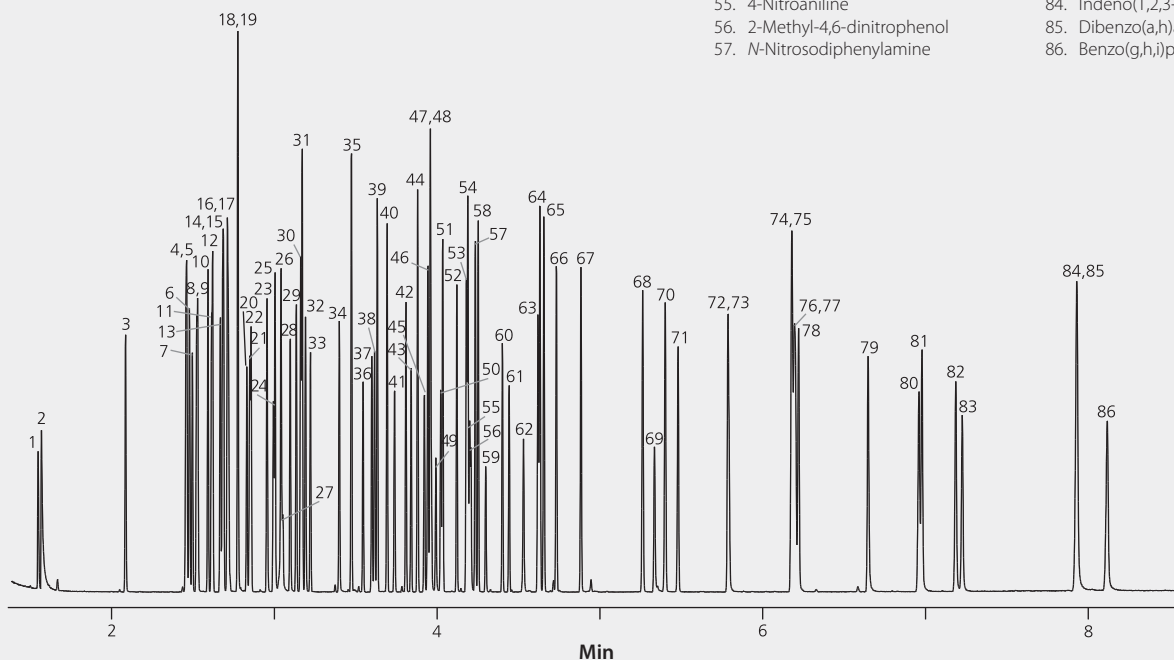


Figure 17. US EPA Method 8270 Semivolatiles on SLB-5ms (0.36 µm)

column: SLB-5ms, 20 m x 0.18 mm I.D., 0.36 µm (28576-U)
 oven: 50 °C (0.50 min), 28 °C/min to 250 °C, 35 °C/min to 340 °C (5 min)
 inj.: 250 °C
 MSD interface: 340 °C
 scan range: m/z 40-450
 carrier gas: helium, 1.4 mL/min constant
 injection: 0.50 µL, reduced pressure to 20 psi at injection (0.1 min)
 (splitter open at 0.75 min)
 liner: 2 mm I.D., straight
 sample: 80-component semivolatile standard at 50 ppm, plus
 6 internal standards (at 40 ppm) in methylene chloride

1. *N*-Nitrosodimethylamine
2. Pyridine
3. 2-Fluorophenol (surr.)
4. Phenol-d₆ (surr.)
5. Phenol
6. Aniline
7. Bis(2-chloroethyl)ether
8. 2-Chlorophenol-d₄ (surr.)
9. 2-Chlorophenol
10. 1,3-Dichlorobenzene
11. 1,4-Dichlorobenzene-d₄ (I.S.)
12. 1,4-Dichlorobenzene
13. Benzyl alcohol
14. 1,2-Dichlorobenzene-d₄ (surr.)
15. 1,2-Dichlorobenzene
16. 2-Methylphenol
17. Bis(2-chloroisopropyl)ether
18. 4-Methylphenol

19. *N*-Nitroso-di-n-propylamine
20. Hexachloroethane
21. Nitrobenzene-d₃ (surr.)
22. Nitrobenzene
23. Isophorone
24. 2-Nitrophenol
25. 2,4-Dimethylphenol
26. Bis(2-chloroethoxy)methane
27. Benzoic acid
28. 2,4-Dichlorophenol
29. 1,2,4-Trichlorobenzene
30. Naphthalene-d₈ (I.S.)
31. Naphthalene
32. 4-Chloroaniline

33. Hexachlorobutadiene
34. 4-Chloro-3-methylphenol
35. 2-Methylnaphthalene
36. Hexachlorocyclopentadiene
37. 2,4,6-Trichlorophenol
38. 2,4,5-Trichlorophenol
39. 2-Fluorobiphenyl (surr.)
40. 2-Chloronaphthalene
41. 2-Nitroaniline
42. Dimethyl phthalate
43. 2,6-Dinitrotoluene
44. Acenaphthylene
45. 3-Nitroaniline
46. Acenaphthene-d₁₀ (I.S.)
47. Acenaphthene
48. 2,4-Dinitrophenol
49. 4-Nitrophenol
50. 2,4-Dinitrotoluene
51. Dibenzofuran
52. Diethyl phthalate
53. 4-Chlorophenyl phenyl ether
54. Fluorene
55. 4-Nitroaniline
56. 2-Methyl-4,6-dinitrophenol
57. *N*-Nitrosodiphenylamine
58. Azobenzene
59. 2,4,6-Tribromophenol (surr.)
60. 4-Bromophenyl phenyl ether
61. Hexachlorobenzene
62. Pentachlorophenol
63. Phenanthrene-d₁₀ (I.S.)
64. Phenanthrene
65. Anthracene
66. Carbazole
67. Di-n-butyl phthalate
68. Fluoranthene
69. Benzidine
70. Pyrene
71. Terphenyl-d₁₄ (surr.)
72. Butylbenzyl phthalate
73. 3,3'-Dimethylbenzidine
74. Bis(2-ethylhexyl)phthalate
75. 3,3'-Dichlorobenzidine
76. Benzo(a)anthracene
77. Chrysene-d₁₂ (I.S.)
78. Chrysene
79. Di-n-octyl phthalate
80. Benzo(b)fluoranthene
81. Benzo(k)fluoranthene
82. Benzo(a)pyrene
83. Perylene-d₁₂ (I.S.)
84. Indeno(1,2,3-cd)pyrene
85. Dibenzo(a,h)anthracene
86. Benzo(g,h,i)perylene

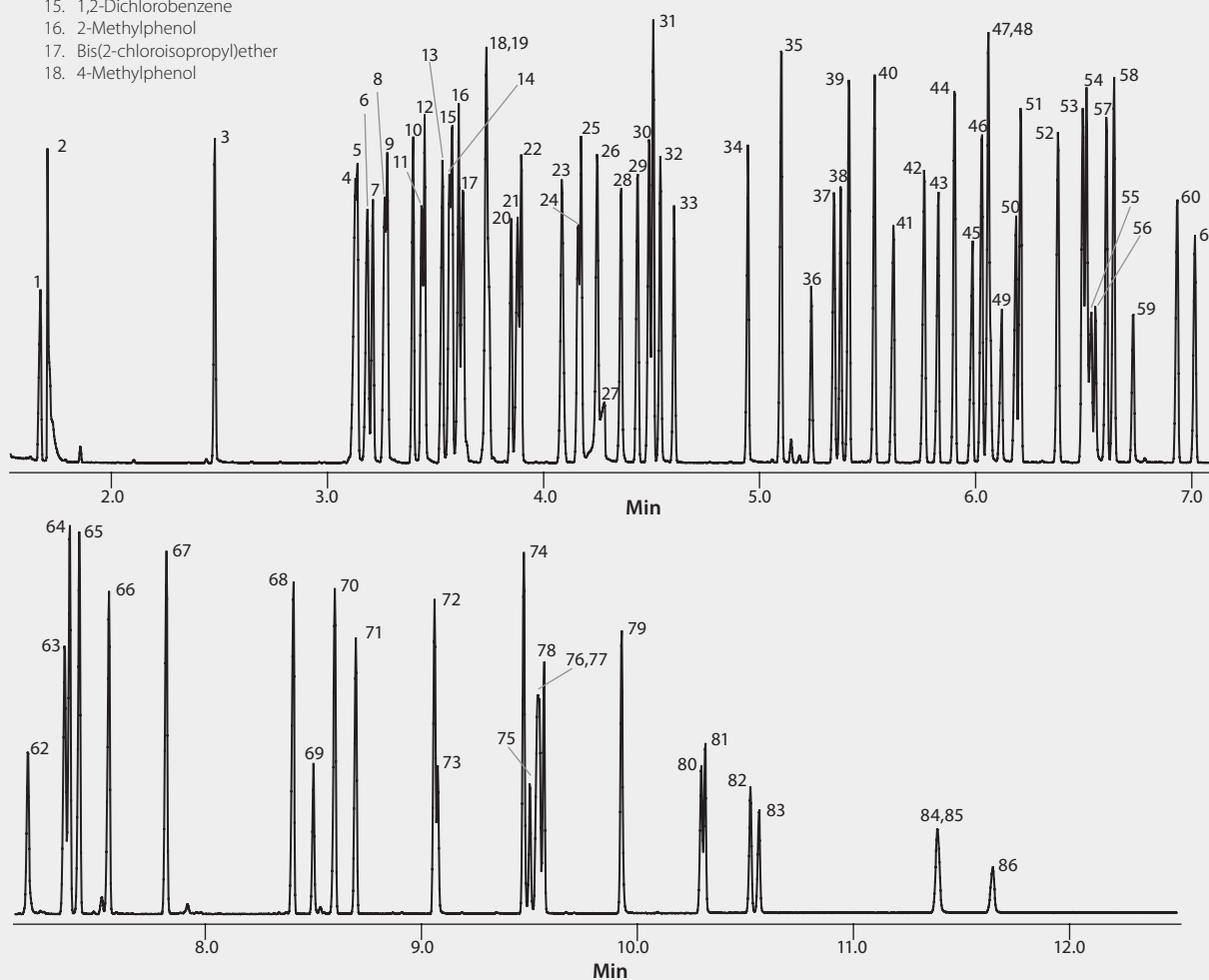


Figure 18. US EPA Method 8081 Organochlorine Pesticides on SLB-5ms

column: SLB-5ms, 15 m x 0.10 mm I.D., 0.10 μm (28466-U)
 oven: 100 °C, 25 °C/min to 325 °C
 inj.: 225 °C
 det.: ECD, 300 °C
 carrier gas: hydrogen, 40 cm/sec constant
 injection: 2 μL, splitless (0.75 min)
 liner: 4 mm I.D., single taper
 sample: 50 ppb of a 22-component chlorinated pesticide standard in n-hexane

- | | |
|--|--------------------------------|
| 1. Tetrachloro- <i>m</i> -xylene (surr.) | 12. 4,4'-DDE |
| 2. α-BHC | 13. Dieldrin |
| 3. β-BHC | 14. Endrin |
| 4. γ-BHC | 15. 4,4'-DDD |
| 5. δ-BHC | 16. Endosulfan II |
| 6. Heptachlor | 17. Endrin aldehyde |
| 7. Aldrin | 18. 4,4'-DDT |
| 8. Heptachlor epoxide | 19. Endosulfan sulfate |
| 9. γ-Chlordane | 20. Methoxychlor |
| 10. Endosulfan I | 21. Endrin ketone |
| 11. α-Chlordane | 22. Decachlorobiphenyl (surr.) |

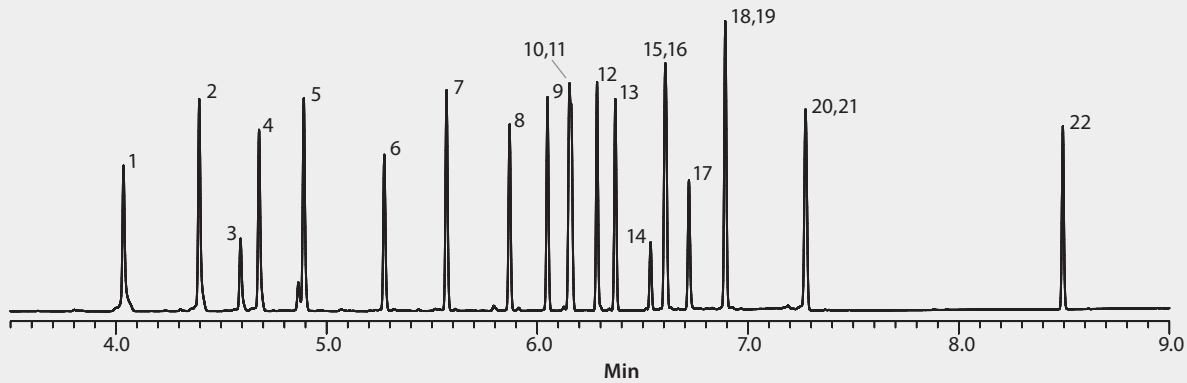


Figure 19. US EPA Method 8081 Organochlorine Pesticides on Equity-1701

column: Equity-1701, 15 m x 0.10 mm I.D., 0.10 μm (28343-U)
 oven: 100 °C, 25 °C/min to 280 °C
 inj.: 225 °C
 det.: ECD, 300 °C
 carrier gas: hydrogen, 40 cm/sec constant
 injection: 2 μL, splitless (0.75 min)
 liner: 4 mm I.D., single taper
 sample: 50 ppb of a 22-component chlorinated pesticide standard in n-hexane

- | | |
|--|--------------------------------|
| 1. Tetrachloro- <i>m</i> -xylene (surr.) | 12. 4,4'-DDE |
| 2. α-BHC | 13. Dieldrin |
| 3. β-BHC | 14. Endrin |
| 4. γ-BHC | 15. 4,4'-DDD |
| 5. δ-BHC | 16. Endosulfan II |
| 6. Heptachlor | 17. Endrin aldehyde |
| 7. Aldrin | 18. 4,4'-DDT |
| 8. Heptachlor epoxide | 19. Endosulfan sulfate |
| 9. γ-Chlordane | 20. Methoxychlor |
| 10. Endosulfan I | 21. Endrin ketone |
| 11. α-Chlordane | 22. Decachlorobiphenyl (surr.) |

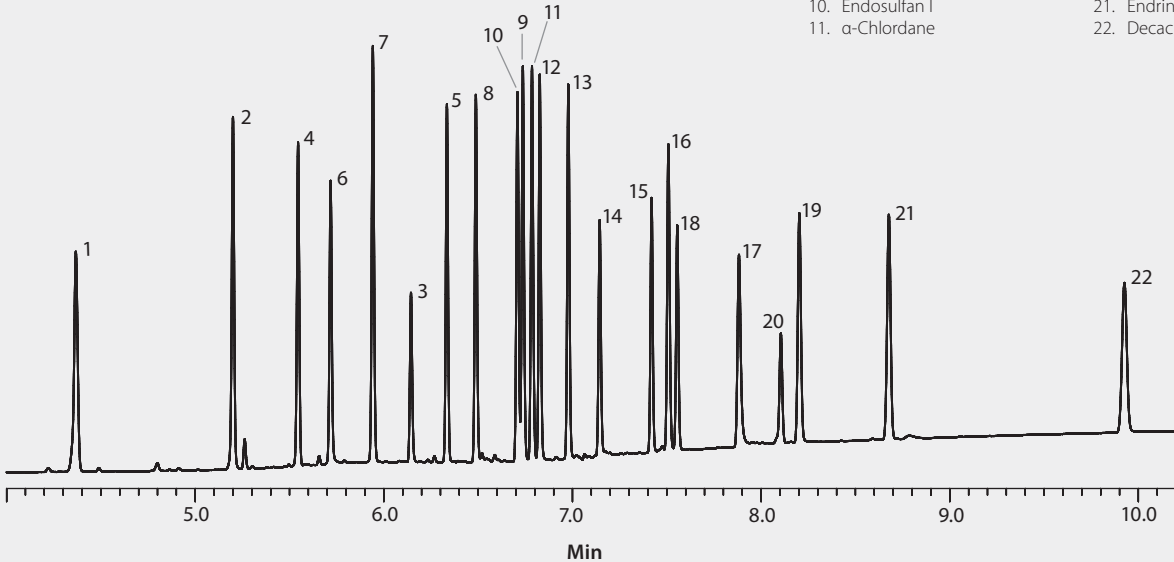


Figure 20. US EPA Method 8082 PCBs as Aroclors on SLB-5ms

column: SLB-5ms, 15 m × 0.10 mm I.D., 0.10 μm (28466-U)
 oven: 80 °C (0.5 min), 50 °C/min to 200 °C, 35 °C/min to 360 °C (2 min)
 inj.: 225 °C
 det.: ECD, 360 °C
 carrier gas: hydrogen, 40 cm/sec constant
 injection: 2 μL, splitless (0.75 min)
 liner: 4 mm I.D., single taper
 sample: Aroclor standard mix 1 (46846-U) diluted to 500 ppb/50 ppb (Aroclors/surrogates) in n-hexane

1. Tetrachloro-*m*-xylene (surr.)
2. Aroclor 1016
3. Aroclor 1260
4. Decachlorobiphenyl (surr.)

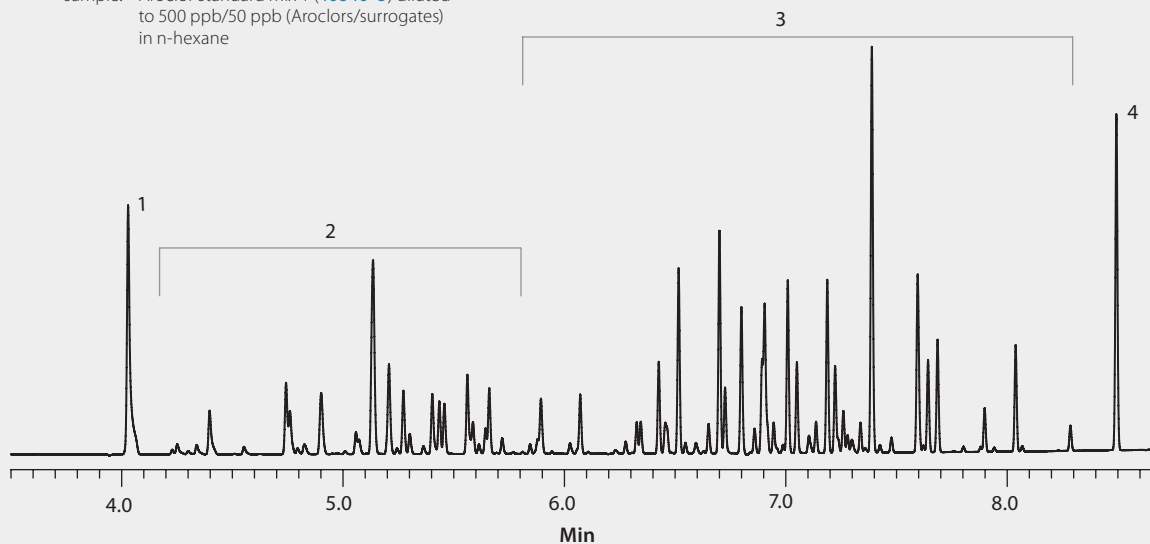
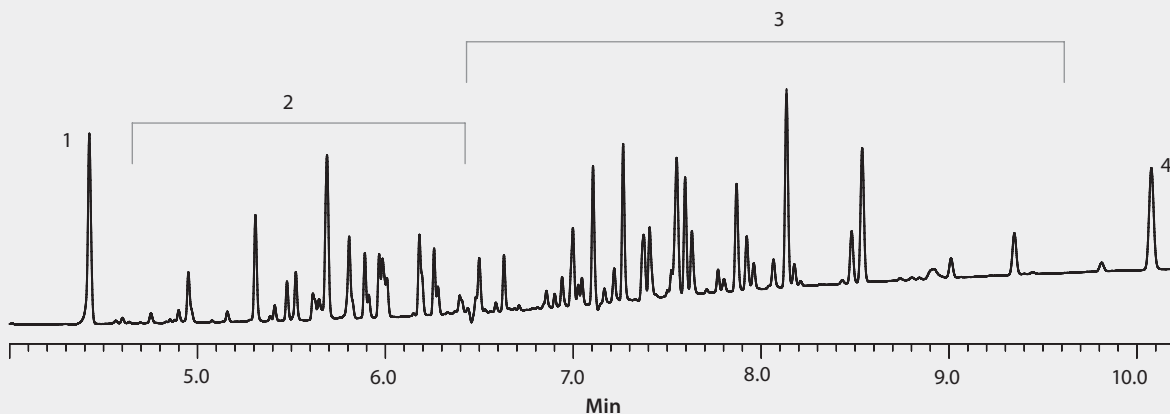


Figure 21. US EPA Method 8082 PCBs as Aroclors on Equity-1701

column: Equity-1701, 15 m × 0.10 mm I.D., 0.10 μm (28343-U)
 oven: 90 °C, 35 °C/min to 280 °C (3 min)
 inj.: 250 °C
 det.: ECD, 280 °C
 carrier gas: hydrogen, 50 cm/sec constant
 injection: 2 μL, splitless (0.75 min)
 liner: 4 mm I.D., single taper
 sample: Aroclor standard mix 1 (46846-U) diluted to 200 ppb/20 ppb (Aroclors/surrogates) in n-hexane

1. Tetrachloro-*m*-xylene (surr.)
2. Aroclor 1016
3. Aroclor 1260
4. Decachlorobiphenyl (surr.)



Petroleum/Chemical Applications

Figure 22. Unleaded Gasoline on Equity-1

column: Equity-1, 15 m × 0.10 mm I.D., 0.10 μm (28039-U)
 oven: 40 °C (1 min), 45 °C/min to 150 °C (2 min)
 inj.: 175 °C
 det.: FID, 175 °C
 carrier gas: hydrogen, 45 cm/sec constant
 injection: 0.1 μL, 300:1 split
 liner: 2 mm I.D., straight
 sample: unleaded gasoline (refinery standard), neat

- | | |
|----------------------------|---------------------------------|
| 1. Isobutane | 26. <i>m</i> - <i>p</i> -Xylene |
| 2. Butane | 27. <i>o</i> -Xylene |
| 3. Isopentane | 28. Nonane |
| 4. Pentane | 29. iso-Propylbenzene |
| 5. 2,2-Dimethylbutane | 30. Propylbenzene |
| 6. 2,3-Dimethylbutane | 31. 1-Methyl-3-ethylbenzene |
| 7. 2-Methylpentane | 32. 1-Methyl-4-ethylbenzene |
| 8. 3-Methylpentane | 33. 1,3,5-Trimethylbenzene |
| 9. Hexane | 34. 3,3,4-Trimethylheptane |
| 10. 2,4-Dimethylpentane | 35. 1-Methyl-2-ethylbenzene |
| 11. Benzene | 36. 1,2,4-Trimethylbenzene |
| 12. 2-Methylhexane | 37. iso-Butylbenzene |
| 13. 2,3-Dimethylpentane | 38. <i>sec</i> -Butylbenzene |
| 14. 3-Methylhexane | 39. 1,2,3-Trimethylbenzene |
| 15. Isooctane | 40. Indane |
| 16. Heptane | 41. 1,3-Diethylbenzene |
| 17. 2,5-Dimethylhexane | 42. <i>N</i> -Butylbenzene |
| 18. 2,4-Dimethylhexane | 43. 1,4-Dimethyl-2-ethylbenzene |
| 19. 2,3,4-Trimethylpentane | 44. 1,3-Dimethyl-4-ethylbenzene |
| 20. Toluene | 45. 1,2-Dimethyl-4-ethylbenzene |
| 21. 2,3-Dimethylhexane | 46. 1,2,4,5-Tetramethylbenzene |
| 22. 2-Methylheptane | 47. 1,2,3,5-Tetramethylbenzene |
| 23. 3-Methylheptane | 48. Naphthalene |
| 24. Octane | 49. 2-Methylnaphthalene |
| 25. Ethylbenzene | 50. 1-Methylnaphthalene |
| | 51. Dimethylnaphthalenes |

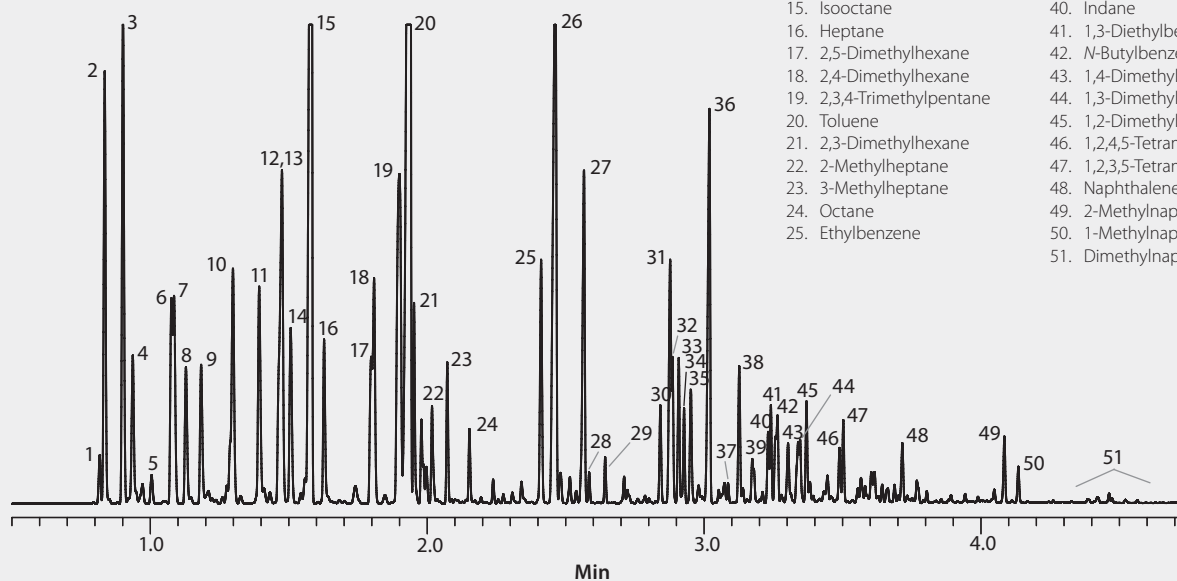


Figure 23. Fuel Oil #2 on Equity-1

1. Fuel Oil #2 pattern

column: Equity-1, 15 m × 0.10 mm I.D., 0.10 μm (28039-U)
 oven: 80 °C, 50 °C/min to 325 °C
 inj.: 250 °C
 det.: FID, 350 °C
 carrier gas: hydrogen, 45 cm/sec constant
 injection: 0.3 μL, 100:1 split, 0.02 min pre-injection dwell time
 liner: 2 mm I.D., straight
 sample: no. 2 fuel oil standard, 20 mg/mL in methanol (47515-U)

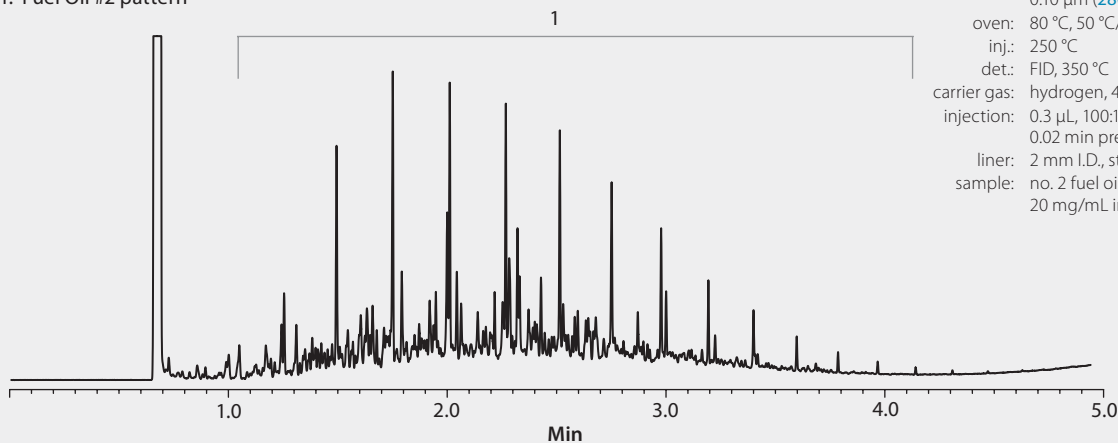


Figure 24. Kerosene on SLB-5ms

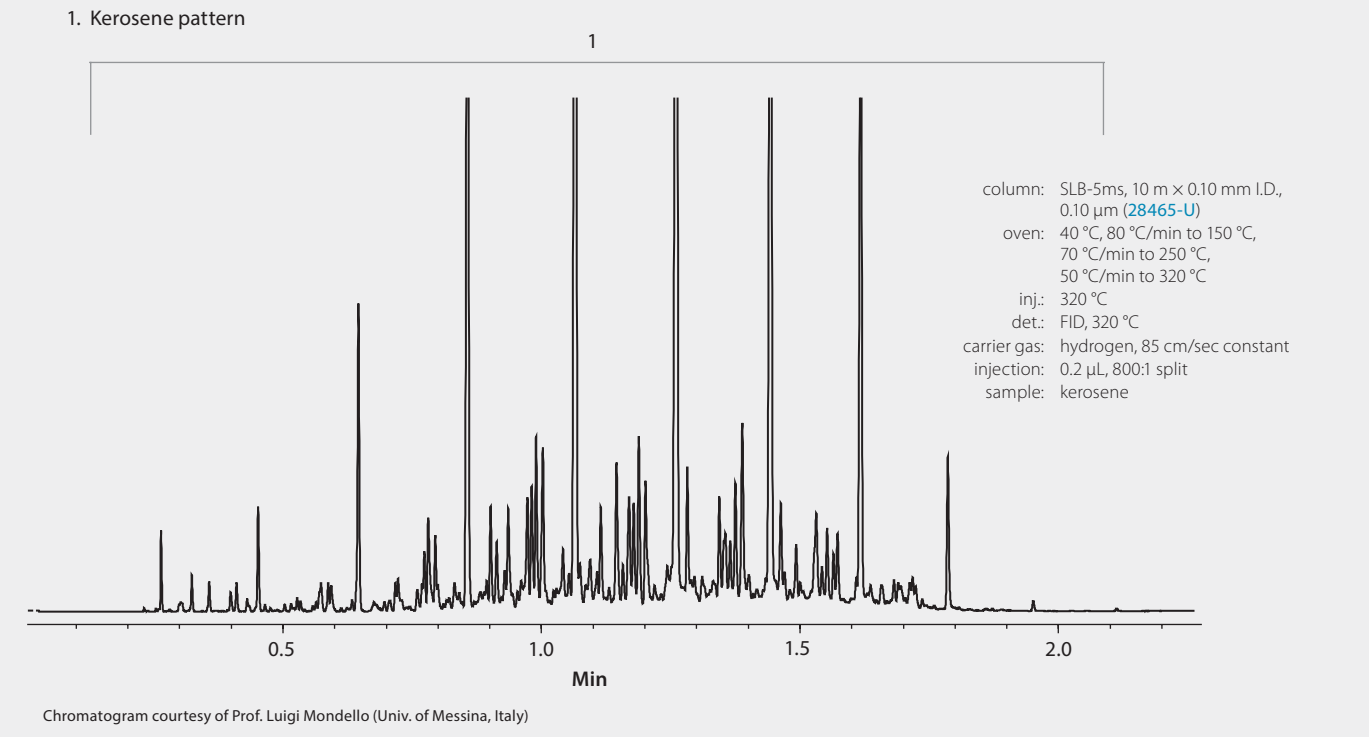
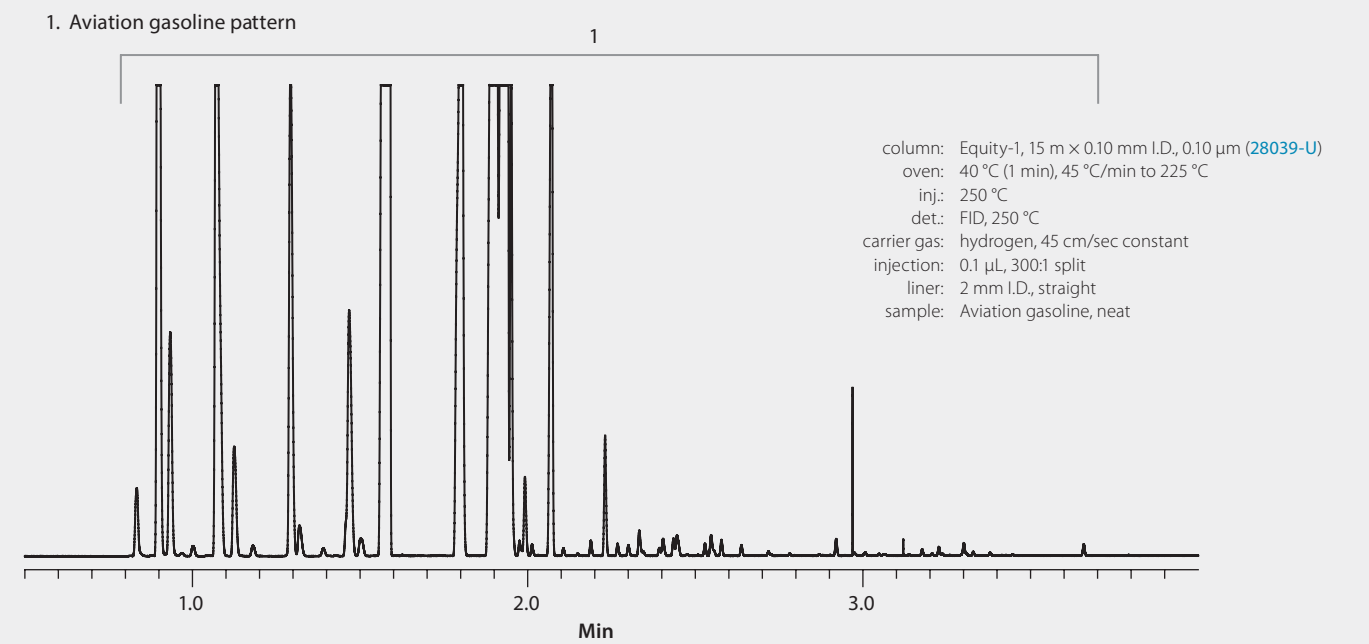


Figure 25. Aviation Gasoline on Equity-1



Food and Beverage Applications

Figure 26. PUFA No. 1 Mix (Marine Source) FAMES on Omegawax

column: Omegawax 100, 15 m × 0.10 mm I.D., 0.10 μm (23399-U)
 oven: 140 °C, 40 °C/min to 280 °C (2 min)
 inj.: 250 °C
 det.: FID, 280 °C
 carrier gas: hydrogen, 50 cm/sec constant
 injection: 0.2 μL, 200:1 split
 liner: 4 mm I.D., split, cup design
 sample: PUFA No. I - Marine Source (47033), diluted to 50 mg/mL in methylene chloride

1. C14:0
2. C16:0
3. C16:1n7
4. C18:1n9
5. C18:1n7
6. C18:2n6
7. C18:3n3
8. C18:4n3
9. C20:1n11
10. C20:1n9
11. C20:1n7
12. C20:4n6
13. C20:4n3
14. C20:5n3
15. C22:1n11
16. C22:1n9
17. C22:5n3
18. C22:6n3

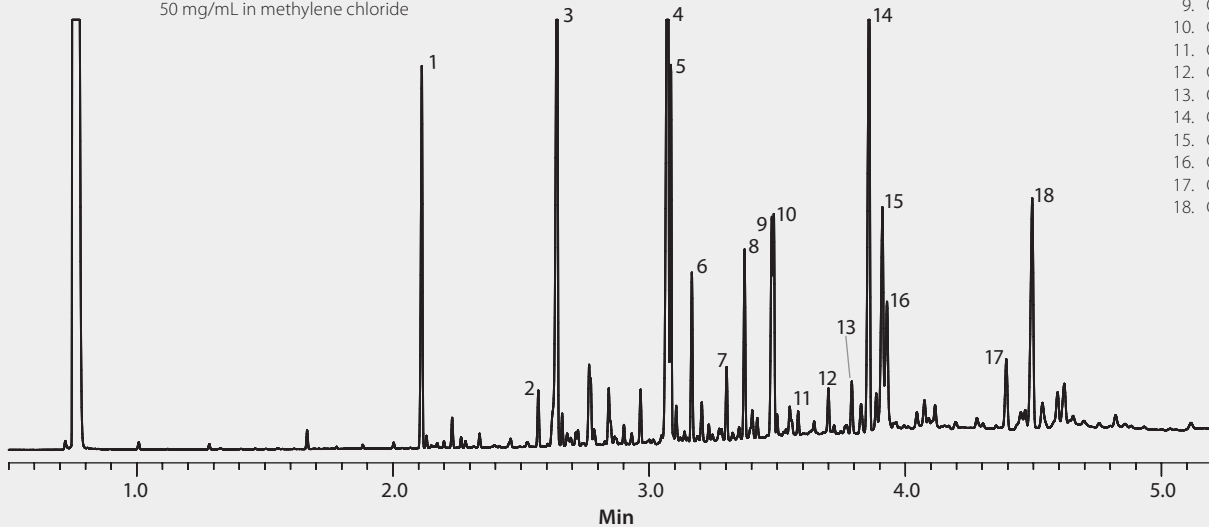


Figure 27. PUFA No. 2 Mix (Animal Source) FAMES on Omegawax

column: Omegawax 100, 15 m × 0.10 mm I.D., 0.10 μm (23399-U)
 oven: 140 °C, 40 °C/min to 280 °C (2 min)
 inj.: 250 °C
 det.: FID, 280 °C
 carrier gas: hydrogen, 50 cm/sec constant
 injection: 0.2 μL, 200:1 split
 liner: 4 mm I.D., split, cup design
 sample: PUFA No. II - Animal Source (47015-U), diluted to 50 mg/mL in methylene chloride

1. C16:0
2. C18:0
3. C18:1n9
4. C18:1n7
5. C18:2n6
6. C18:3n6
7. C20:0
8. C20:1n9
9. C20:2n9
10. C20:3n6
11. C20:4n6
12. C20:5n3
13. C22:5n6
14. C22:5n3
15. C22:6n3

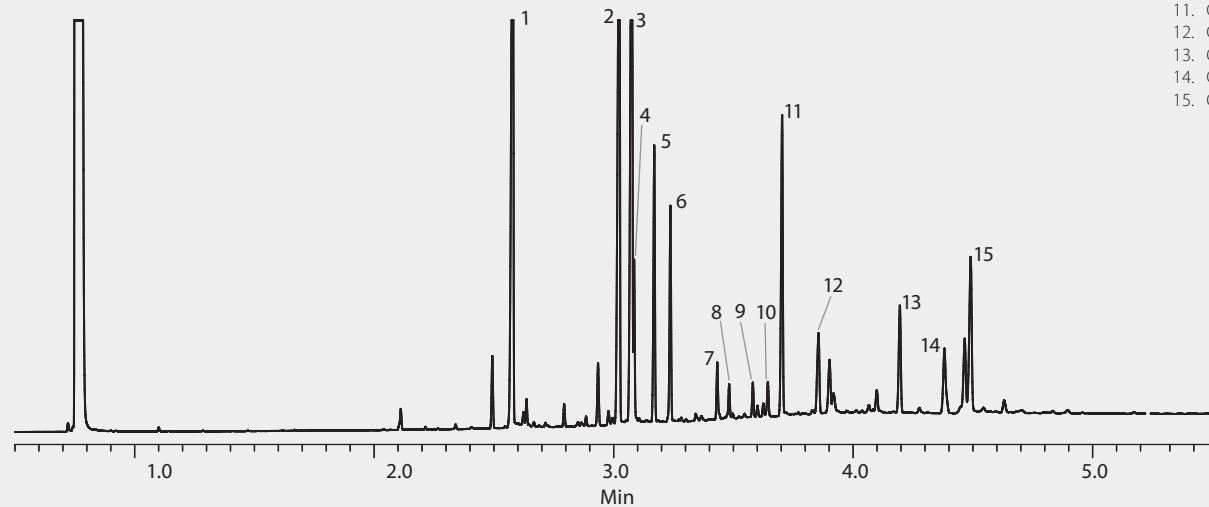
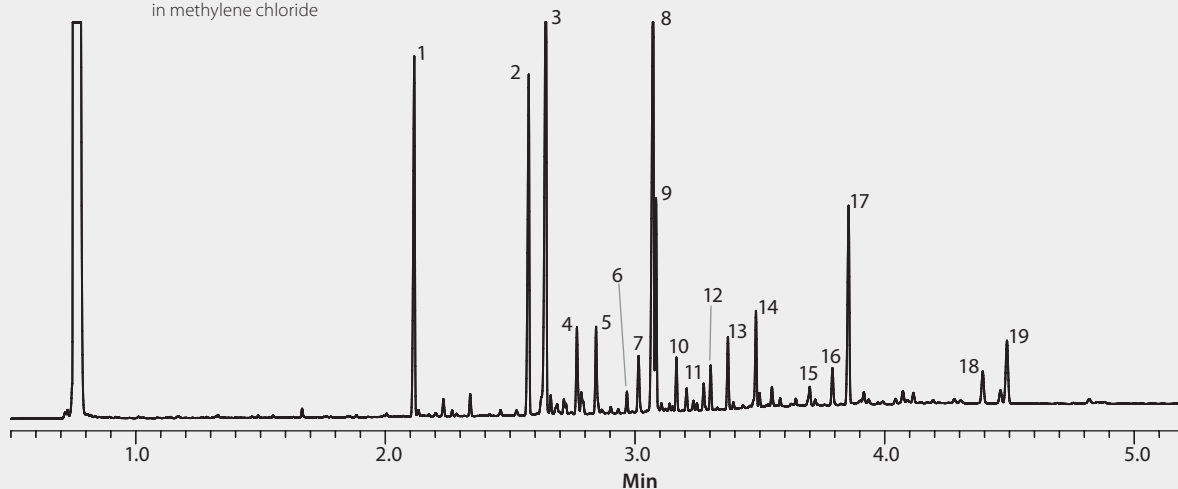


Figure 28. PUFA No. 3 Mix (Menhaden Oil) FAMES on Omegawax

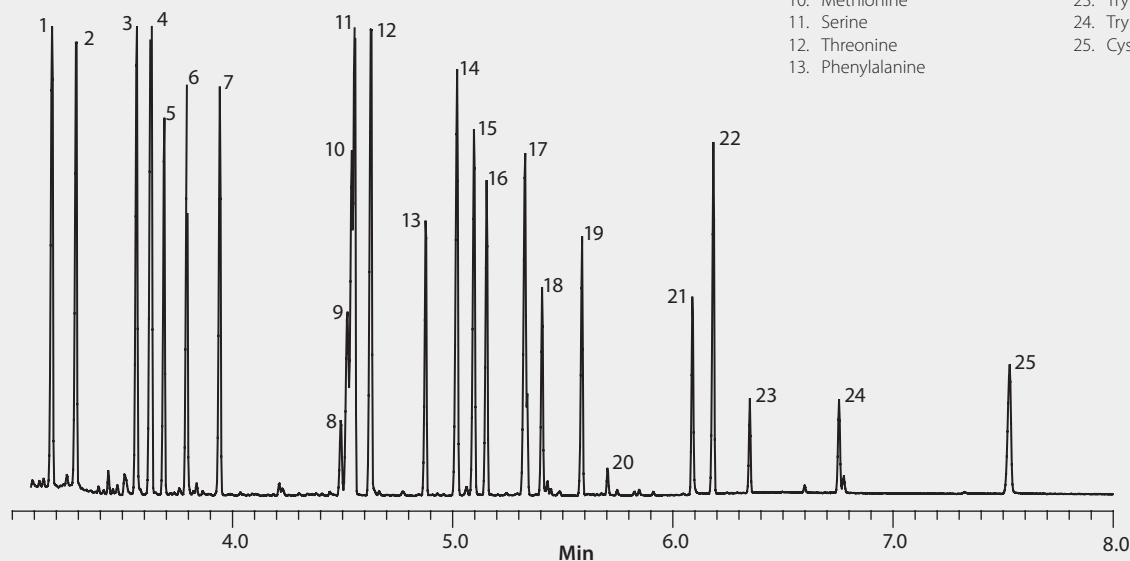
column: Omegawax 100, 15 m x 0.10 mm I.D., 0.10 μ m (23399-U)
 oven: 140 $^{\circ}$ C, 40 $^{\circ}$ C/min to 280 $^{\circ}$ C (2 min)
 inj.: 250 $^{\circ}$ C
 det.: FID, 280 $^{\circ}$ C
 carrier gas: hydrogen, 50 cm/sec constant
 injection: 0.2 μ L, 200:1 split
 liner: 4 mm I.D., split, cup design
 sample: PUFA No. III – Menhaden Oil (47085-U), diluted to 50 mg/mL
 in methylene chloride



1. C14:0
2. C16:0
3. C16:1n7
4. C16:2n4
5. C16:3n4
6. C16:4n1
7. C18:0
8. C18:1n9
9. C18:1n7
10. C18:2n6
11. C18:3n4
12. C18:3n3
13. C18:4n3
14. C20:1n9
15. C20:4n6
16. C20:4n3
17. C20:5n3
18. C22:5n3
19. C22:6n3

Figure 29. Amino Acids on SLB-5ms

column: SLB-5ms, 20 m x 0.18 mm I.D., 0.18 μ m (28564-U)
 oven: 100 $^{\circ}$ C (1 min.), 35 $^{\circ}$ C/min to 290 $^{\circ}$ C (3 min), 40 $^{\circ}$ C/min to 360 $^{\circ}$ C
 inj. temp.: 250 $^{\circ}$ C
 detector: MSD, scan range m/z 40-450
 MSD interface: 325 $^{\circ}$ C
 carrier gas: helium, 1 mL/min
 injection: 0.5 μ L, splitless (1.0 min)
 liner: 2 mm I.D., splitless type, straight design
 sample: TBDMS derivatives of amino acids, each approximately 23 μ g/mL



- | | |
|---------------------------------|---------------------------------|
| 1. Alanine | 14. Aspartic acid |
| 2. Glycine | 15. Hydroxyproline |
| 3. Valine | 16. Cysteine |
| 4. Artifact from derivatization | 17. Glutamic acid |
| 5. Leucine | 18. Asparagine |
| 6. Isoleucine | 19. Lysine |
| 7. Proline | 20. Glutamine |
| 8. Asparagine extra derivative | 21. Histidine |
| 9. Glutamine extra derivative | 22. Tyrosine |
| 10. Methionine | 23. Tryptophan extra derivative |
| 11. Serine | 24. Tryptophan |
| 12. Threonine | 25. Cystine |
| 13. Phenylalanine | |

Flavor and Fragrance/Cosmetic Applications

Figure 30. Lemon Essential Oil on SLB-5ms

column: SLB-5ms, 10 m x 0.10 mm I.D.,
0.10 μm (28465-U)
oven: 40 °C, 50 °C/min to 320 °C
inj.: 320 °C
det.: FID, 320 °C
carrier gas: hydrogen, 81.5 cm/sec constant
injection: 0.4 μL, 300:1 split
sample: lemon essential oil in hexane

- | | | | |
|-------------------|----------------------------------|----------------------------------|----------------------|
| 1. Tricyclene | 10. δ-3-Carene | 19. Linalool | 28. α-Terpineol |
| 2. α-Thujene | 11. α-Terpinene | 20. Nonanal | 29. Decanal |
| 3. α-Pinene | 12. <i>p</i> -Cymene | 21. <i>cis</i> -Limonene oxide | 30. Citronellol |
| 4. Camphene | 13. Limonene | 22. <i>trans</i> -Limonene oxide | 31. Nerol |
| 5. Sabinene | 14. (E)-β-Ocimene | 23. (E)-Myroxide | 32. Neral |
| 6. β-Pinene | 15. γ-Terpinene | 24. Camphor | 33. Carvone |
| 7. Myrcene | 16. <i>cis</i> -Sabinene hydrate | 25. Citronellal | 34. Geraniol |
| 8. Octanal | 17. Octanol | 26. Borneol | 35. Geranial |
| 9. α-Phellandrene | 18. Terpinolene | 27. Terpinen-4-ol | 36. Perilla aldehyde |

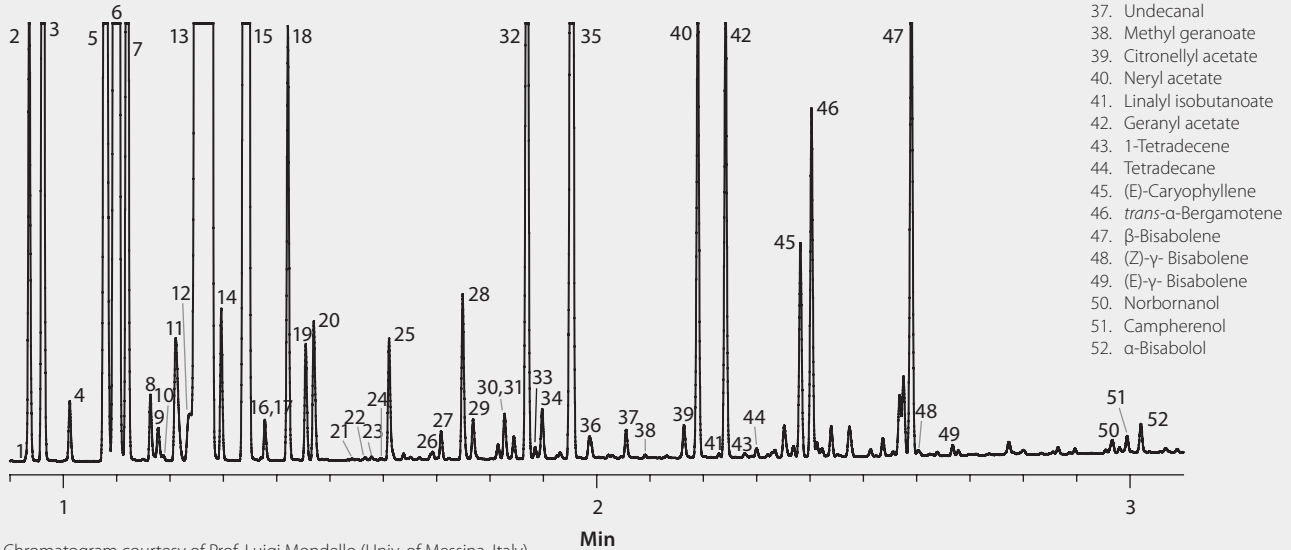


Figure 31. Distilled Lime Essential Oil on Equity-1

column: Equity-1, 15 m x 0.10 mm I.D., 0.10 μm (28039-U)
oven: 75 °C (1 min), 35 °C/min to 200 °C (1 min)
inj.: 250 °C
det.: FID, 250 °C
carrier gas: helium, 45 cm/sec constant
injection: 0.10 μL, 300:1 split
liner: 2 mm I.D., straight
sample: distilled lime oil, neat

- | |
|---------------------------------|
| 1. α-Pinene |
| 2. Camphene |
| 3. β-Pinene |
| 4. Myrcene |
| 5. α-Phellandrene |
| 6. 1,4-Cineole |
| 7. α-Terpinene |
| 8. <i>p</i> -Cymene |
| 9. δ-Limonene |
| 10. γ-Terpinene |
| 11. Terpinolene |
| 12. Linalool |
| 13. α-Fenyl alcohol |
| 14. Terpinen-1-ol |
| 15. β-Terpineol |
| 16. Borneol |
| 17. Terpinen-4-ol |
| 18. α-Terpineol |
| 19. γ-Terpineol |
| 20. Decanal |
| 21. Neral |
| 22. Geranial |
| 23. Neral acetate |
| 24. Geranyl acetate |
| 25. Dodecanal |
| 26. β-Carophyllene |
| 27. <i>trans</i> -α-Bergamotene |
| 28. <i>trans</i> -α-Farnesene |
| 29. β-Bisabolene |

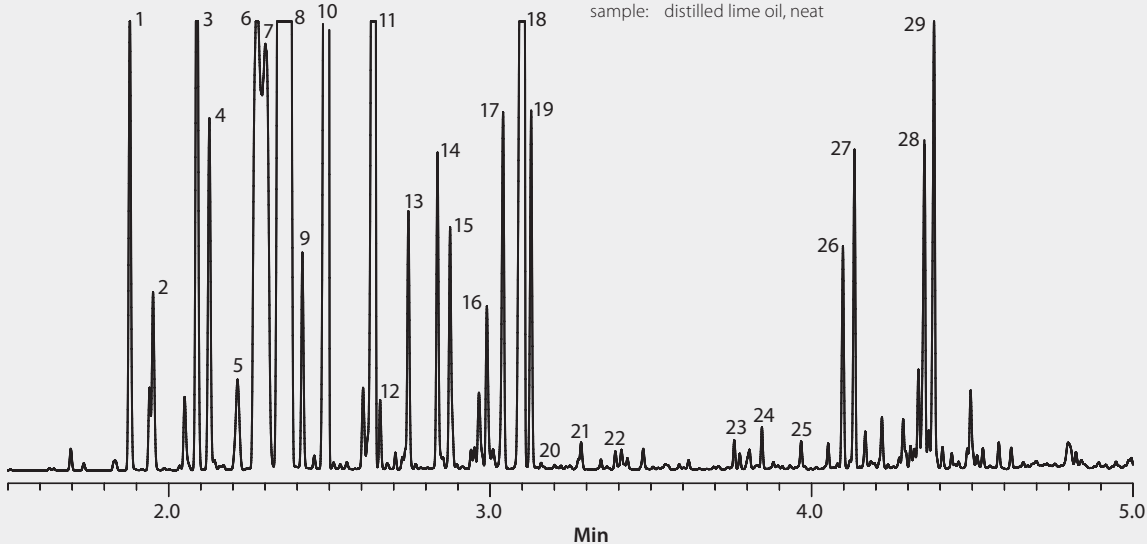
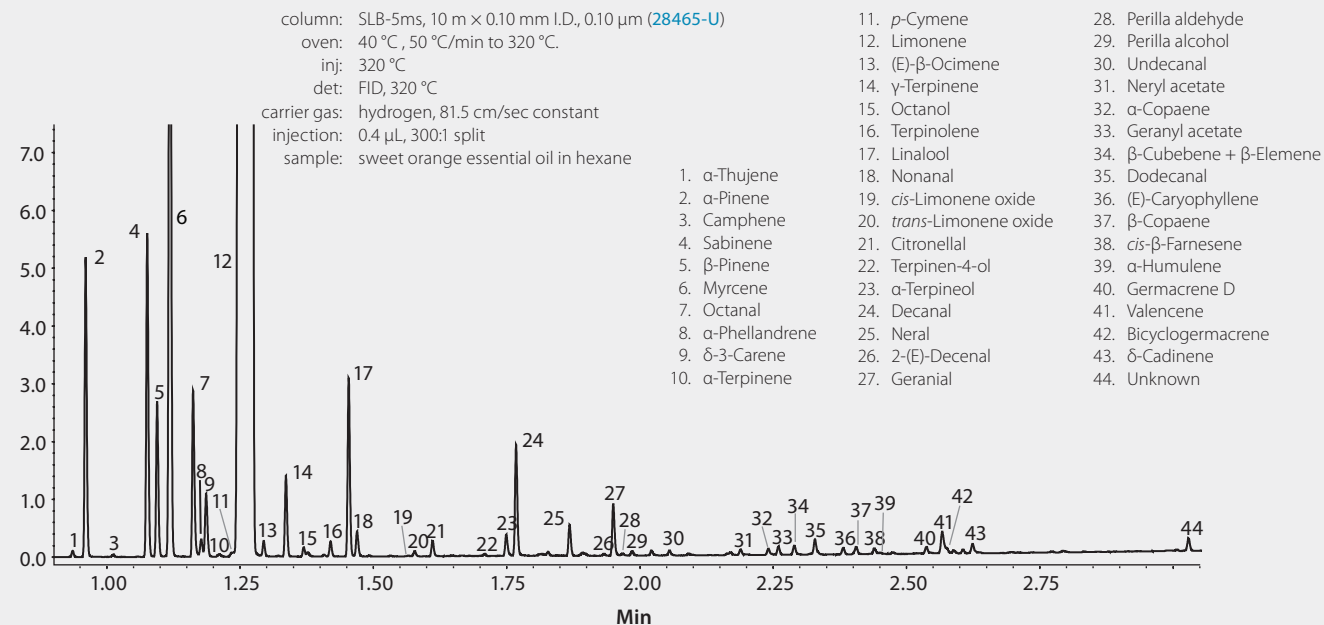
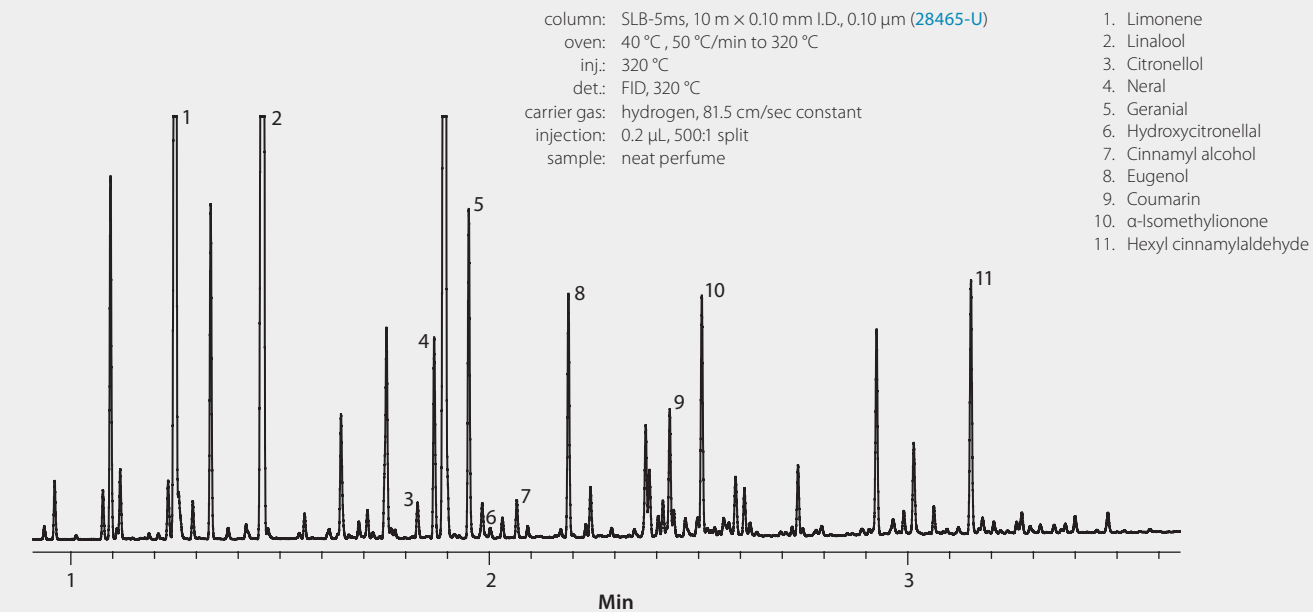


Figure 32. Sweet Orange Essential Oil on SLB-5ms**Figure 33. Allergens in Commercial Perfume on SLB-5ms**

Clinical Applications

Figure 34. Bacterial Acid Methyl Esters (BAMEs) on Equity-1

column: Equity-1, 15 m x 0.10 mm I.D., 0.10 μm (28039-U)
 oven: 175 °C, 30 °C/min to 275 °C (1 min)
 inj.: 280 °C
 det.: FID, 280 °C
 carrier gas: hydrogen, 45 cm/sec constant
 injection: 0.5 μL, split 200:1
 liner: 4 mm I.D., split, cup design
 sample: Bacterial Acid Methyl Ester (BAME) Mix (47080-U)

9. Methyl 3-hydroxytetradecanoate (3-OH C14:0)
10. Methyl pentadecanoate (C15:0)
11. Methyl 13-methyltetradecanoate (iC15:0)
12. Methyl 12-methyltetradecanoate (a-C15:0)
13. Methyl hexadecanoate (C16:0)
14. Methyl 14-methylpentadecanoate (iC16:0)
15. Methyl 2-hydroxyhexadecanoate (2-OH C16:0)
16. Methyl cis-9-hexadecenoate (C16:1⁹)
17. Methyl heptadecanoate (C17:0)
18. Methyl 15-methylhexadecanoate (iC17:0)
19. Methyl cis-9,10-methylenehexadecanoate (C17:0⁹)
20. Methyl octadecanoate (C18:0)
21. Methyl cis-9-octadecenoate (C18:1⁹)
22. Methyl trans-9-octadecenoate (C18:1⁹) & Methyl cis-11-octadecenoate (C18:1¹¹)
23. Methyl cis-9,12-octadecadienoate (C18:2^{9,12})
24. Methyl nonadecanoate (C19:0)
25. Methyl cis-9,10-methyleneoctadecanoate (C19:0⁹)
26. Methyl eicosanoate (C20:0)

1. Methyl 2-hydroxydecanoate (2-OH C10:0)
2. Methyl undecanoate (C11:0)
3. Methyl dodecanoate (C12:0)
4. Methyl 2-hydroxydodecanoate (2-OH C12:0)
5. Methyl 3-hydroxydodecanoate (3-OH C12:0)
6. Methyl tridecanoate (C13:0)
7. Methyl tetradecanoate (C14:0)
8. Methyl 2-hydroxytetradecanoate (2-OH C14:0)

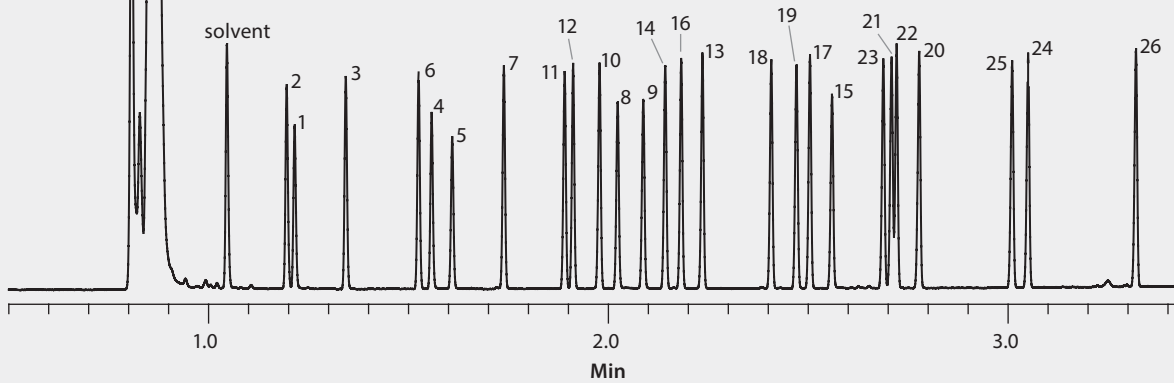
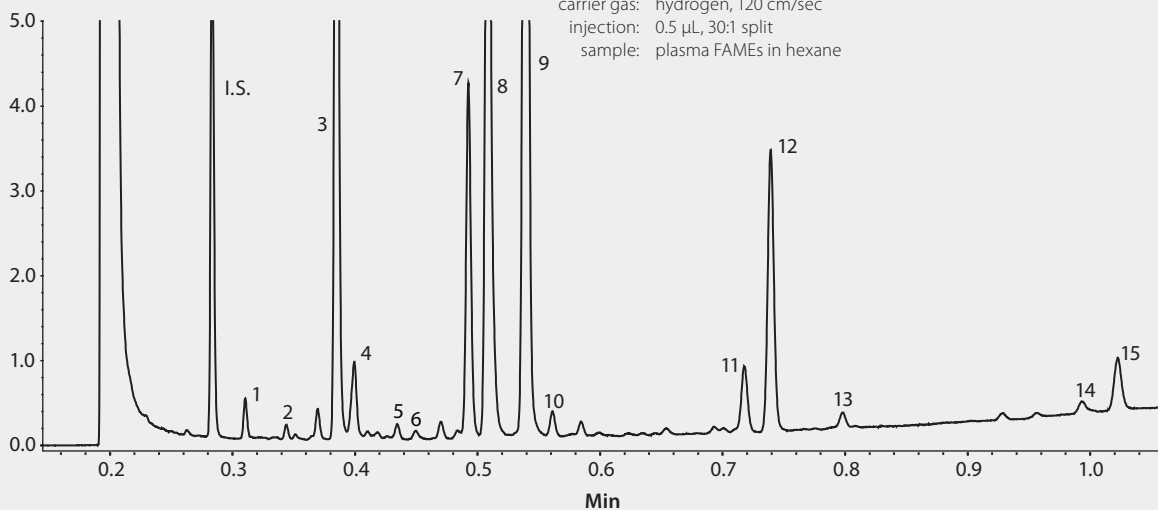


Figure 35. FAMES in Plasma on SUPELCOWAX 10

column: SUPELCOWAX 10, 10 m x 0.10 mm I.D., 0.10 μm (25026-U)
 oven: 220 °C, 60 °C/min to 280 °C (1 min)
 inj. temp.: 280 °C
 detector: FID, 280 °C
 carrier gas: hydrogen, 120 cm/sec
 injection: 0.5 μL, 30:1 split
 sample: plasma FAMES in hexane

15. C13:0
1. C14:0
2. C15:0
3. C16:0
4. C16:1n7
5. C17:0
6. C16:3n4
7. C18:0
8. C18:1n9
9. C18:2n6
10. C18:3n3
11. C20:3n6
12. C20:4n6
13. C20:5n3
14. C22:5n3
15. C22:6n3



Chromatogram courtesy of Prof. Luigi Mondello (Univ. of Messina, Italy)

Ordering Information

Analytical GC chemists are continually striving to reduce analysis times, because shorter analysis times increase sample throughput, which translates to the completion of more runs per shift. However, any decrease in analysis time must not diminish the resolution necessary to adequately resolve peaks of interest, or to identify specific elution patterns. Applying the Principles of Fast GC to any application can achieve both objectives. Table 5 lists the catalog numbers of our special purpose, ionic liquid, and general purpose Fast GC columns.

Table 5. Fast GC Columns

Chemistry	I.D. (mm)	d _p (µm)	Length (m)	β Value	Cat. No.
Special Purpose Fast GC Columns					
SLB®-5ms	0.10	0.10	10	250	28465-U
SLB-5ms	0.10	0.10	15	250	28466-U
SLB-5ms	0.18	0.18	20	250	28564-U
SLB-5ms	0.18	0.30	30	150	28575-U
SLB-5ms	0.18	0.36	20	125	28576-U
SPB®-624	0.18	1.00	20	45	28662-U
VOCOL®	0.18	1.00	20	45	28463-U
Equity®-1701	0.10	0.10	15	250	28343-U
Omegawax®	0.10	0.10	15	250	23399-U
SP®-2560	0.18	0.14	75	321	23348-U
Ionic Liquid Fast GC Columns					
SLB®-IL59	0.10	0.08	15	313	28880-U
SLB-IL60	0.10	0.08	15	313	29503-U
SLB-IL60	0.18	0.14	20	313	29504-U
SLB-IL61	0.10	0.08	15	313	29484-U
SLB-IL76	0.10	0.08	15	313	28909-U
SLB-IL82	0.10	0.08	15	313	29477-U
SLB-IL100	0.10	0.08	15	313	28882-U
SLB-IL100	0.18	0.14	20	313	28883-U
SLB-IL111	0.10	0.08	15	313	28925-U
General Purpose Fast GC Columns					
Equity®-1	0.10	0.10	15	250	28039-U
Equity-5	0.10	0.10	15	250	28083-U
SUPELCOWAX® 10	0.10	0.10	5	250	25025-U
SUPELCOWAX 10	0.10	0.10	10	250	25026-U
SUPELCOWAX 10	0.10	0.10	15	250	24343

Our Fast GC webpage contains over 75 Fast GC chromatograms spanning several industries and applications.

For this and additional information, visit

sigma-aldrich.com/fastgc

Column Specifications

Looking for information or specifications for a particular phase? This section provides application, USP code, phase, and temperature limit information for all columns offered with Fast GC dimensions. Temperature limits are for Fast GC dimensions only.

Equity®-1

- Application: This column is designed for general purpose applications where a non-polar column is required. Analytes will be separated primarily according to boiling point.
- USP Code: This column meets USP G1, G2 and G9 requirements.
- Phase: Bonded; poly(dimethyl siloxane)
- Temp. Limits: -60 °C to 325 °C (isothermal) or 350 °C (programmed)

SLB®-5ms

- Application: The 5% phenyl equivalent phase provides a boiling point elution order with a slight increase in selectivity, especially for aromatic compounds. The low bleed characteristics, inertness, and durable nature make it the column of choice for environmental analytes (such as semivolatiles, pesticides, PCBs, and herbicides) or anywhere a low bleed non-polar column is required.
- USP Code: This column meets USP G27 and G36 requirements.
- Phase: Bonded and highly crosslinked; silphenylene polymer virtually equivalent in polarity to poly(5% diphenyl/95% dimethyl siloxane)
- Temp. Limits: -60 °C to 340 °C (isothermal) or 360 °C (programmed)

Equity®-5

- Application: This popular column is designed for general purpose applications where a non-polar column is required. The low phenyl content provides thermal stability compared to 100% poly(dimethyl siloxane) columns.
- USP Code: This column meets USP G27 and G36 requirements.
- Phase: Bonded; poly(5% diphenyl/95% dimethyl siloxane)
- Temp. Limits: -60 °C to 325 °C (isothermal) or 350 °C (programmed)

SPB®-624

- Application: This column is specially tested for separation, efficiency, and low bleed. It is designed for purge-and-trap analyses of volatile halogenated, non-halogenated, and aromatic contaminants from environmental samples.
- USP Code: This column meets USP G43 requirements.
- Phase: Bonded; proprietary
- Temp. Limits: Subambient to 250 °C (isothermal or programmed)

VOCOL®

- Application: This intermediate polarity column, designed for analyses of volatile organic compounds (VOCs), offers great retention and resolution of highly volatile compounds. Use this column in direct injection ports or coupled to purge-and-trap systems.
- USP Code: None
- Phase: Bonded; proprietary
- Temp. Limits: Subambient to 250 °C (isothermal or programmed)

Equity®-1701

- Application: Increased phase polarity, due to cyanopropylphenyl functional group substitution, offers unique selectivity compared to other phases. This column works well with systems employing ECD, NPD, and MSD detectors, and is often used for alcohols, oxygenates, pharmaceuticals, pesticides, and PCB applications.
- USP Code: This column meets G46 requirements
- Phase: Bonded; poly(14% cyanopropylphenyl/86% dimethyl siloxane)
- Temp. Limits: Subambient to 280 °C (isothermal or programmed)

Omegawax®

- Application: This column allows highly reproducible analyses of fatty acid methyl esters (FAMEs), specifically the omega 3 and omega 6 fatty acids. It is tested to ensure reproducible FAME equivalent chain length (ECL) values and resolution of key components.
- USP Code: This column meets USP G16 requirements.
- Phase: Bonded; poly(ethylene glycol)
- Temp. Limits: 50 °C to 280 °C (isothermal or programmed)

SUPELCOWAX® 10

- Application: This column is based on one of the most widely used polar phases, Carbowax 20M, and is a polar column suitable for analyses of solvents, fatty acid methyl esters (FAMEs), food, flavor and fragrance compounds, alcohols, and aromatics. Additionally, this column is a great choice when a polar general purpose column is required.
- USP Code: This column meets USP G16 requirements.
- Phase: Bonded; poly(ethylene glycol)
- Temp. Limits: 35 °C to 280 °C (isothermal or programmed)

SLB®-IL59

- Application: Selectivity more polar than PEG/wax phases, resulting in unique elution patterns. Higher maximum temperature than PEG/wax columns (300 °C compared to 270–280 °C). Great choice for analysis of neutral and moderately basic analytes.
- USP Code: None
- Phase: Non-bonded; 1,12-di(triethylphosphonium)dodecane bis(trifluoromethylsulfonyl)imide
- Temp. Limits: Subambient to 300 °C (isothermal or programmed)

SLB®-IL60

- Application: Modified (deactivated) version of SLB-IL59 provides better inertness. Selectivity more polar than PEG/wax phases, resulting in unique elution patterns. Higher maximum temperature than PEG/wax columns (300 °C compared to 270–280 °C). Excellent alternative to existing PEG/wax columns. Also a good GCxGC column choice.
- USP Code: None
- Phase: Non-bonded; 1,12-di(triethylphosphonium)dodecane bis(trifluoromethylsulfonyl)imide
- Temp. Limits: 35 °C to 300 °C (isothermal or programmed)

SLB®-IL61

- Application: The first of our third generation ionic liquid columns. Modified (triflate anion) version of SLB-IL59 increases inertness. Selectivity more polar than PEG/wax phases, resulting in unique elution patterns. Higher maximum temperature than PEG/wax columns (290 °C compared to 270–280 °C). Great choice for analysis of neutral and moderately basic analytes.
- USP Code: None
- Phase: Non-bonded; 1,12-di(triethylphosphonium)dodecane bis(trifluoromethylsulfonyl)imide trifluoromethylsulfonate
- Temp. Limits: 40 °C to 290 °C (isothermal or programmed)

SLB®-IL76

- Application: The first of our second generation ionic liquid columns. Phase structure engineered with numerous interaction mechanisms, resulting in selectivity differences even when compared to columns with similar GC column polarity scale values.
- USP Code: None
- Phase: Non-bonded; tri(triethylphosphoniumhexanamido) triethylamine bis(trifluoromethylsulfonyl)imide
- Temp. Limits: Subambient to 270 °C (isothermal or programmed)

SP®-2560

- Application: This highly polar biscyanopropyl column was specifically designed for detailed separation of geometric-positional (*cis/trans*) isomers of fatty acid methyl esters (FAMES). It is extremely effective for FAME isomer applications.
- USP Code: This column meets USP G5 requirements.
- Phase: Non-bonded; poly(biscyanopropyl siloxane)
- Temp. Limits: Subambient to 250 °C (isothermal or programmed)

SLB®-IL82

- Application: Selectivity slightly more polar than polysiloxane phases with a high percentage of cyanopropyl pendent groups, resulting in unique elution patterns. Great choice for analysis of neutral and moderately basic analytes.
- USP Code: None
- Phase: Non-bonded; 1,12-di(2,3-dimethylimidazolium)dodecane bis(trifluoromethylsulfonyl)imide
- Temp. Limits: 50 °C to 270 °C (isothermal or programmed)

SLB®-IL100

- Application: World's first commercially available ionic liquid GC column. Serves as the benchmark of 100 on our GC column polarity scale. Selectivity almost identical to TCEP phase. Higher maximum temperature than TCEP columns (230 °C compared to 140 °C). Great choice for analysis of neutral and polarizable (contain double and/or triple C–C bonds) analytes.
- USP Code: None
- Phase: Non-bonded; 1,9-di(3-vinylimidazolium)nonane bis(trifluoromethylsulfonyl)imide
- Temp. Limits: Subambient to 230 °C (isothermal or programmed)

SLB®-IL111

- Application: World's first commercial column to rate over 100 on our GC column polarity scale. Selectivity most orthogonal to non-polar and intermediate polar phases, resulting in very unique elution patterns. Maximum temperature of 270 °C is very impressive for such an extremely polar column. Great choice for separation of polarizable analytes (contain double and/or triple C–C bonds) from neutral analytes. Also a good GCxGC column choice.
- USP Code: None
- Phase: Non-bonded; 1,5-di(2,3-dimethylimidazolium)pentane bis(trifluoromethylsulfonyl)imide
- Temp. Limits: 50 °C to 270 °C (isothermal or programmed)

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