SELECTION GUIDE

# Capillary GC Column Selection Guide

Restek offers fused silica or stainless steel capillary columns in more than 900 stock combinations of stationary phase, stationary phase film thickness, column ID, and column length. If you are not sure about how to choose the best combination for your application, column selection can be a frustrating, hit-or-miss decision. The information in this guide can help you choose the proper column for your particular need. Further, it can help you to determine whether a column you already are using is the best choice, or if you might improve resolution, speed of analysis, and/or analyte quantification by using a different column.

**Parameters**

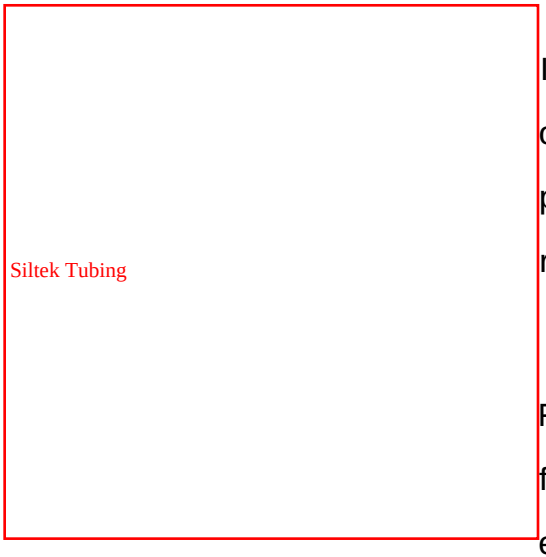
- **Tubing Material**
- **Stationary Phase**
- **Stationary Phase Film Thickness**
- **Column Internal Diameter (ID)**
- **Column Length**

As always, your satisfaction with Restek chromatography columns is guaranteed. Please contact our **Technical Service Group** (or call 800-356-1688 or 814-353-1300,ext. 4), or your **Restek**

SELECTION GUIDE

# Restek Capillary GC Column Selection Guide

## Tubing Material


Siltek Tubing

In either fused silica or stainless steel format, Restek columns offer excellent inertness, consistent column-to-column performance and, when installed and operated according to recommendations, long column lifetimes.

Fused silica Rxi®, Rtx®, or Rt™ columns are your best choice for most applications. They offer the highest coating efficiencies, ensuring the best resolution of closely eluting compounds. Also, many Restek fused silica columns can be ordered with an **Integra-Guard™ integral guard column**.

Rxi® columns, in particular, provide unmatched performance and exceptionally reliable column-to-column consistency. In developing these columns, we focused on achieving unsurpassed inertness, and the lowest bleed and the highest reproducibility possible. To achieve these goals, we hired the world's best polymer chemists and built a new state-of-the-art research facility. We established rigorous controls on tubing dimensions and surface activity, and we treat this highly uniform tubing with a unique deactivation chemistry, producing a consistent, inert surface on which to apply a polymer. We reformulated our polymers, ensuring neutrality and fine tuning

selectivity for retention time locking.

The resulting exceptionally low-bleed columns are ideal for trace-level GC/MS analysis: with an Rxi® column, you can chromatograph sub-nanogram levels of active acidic or basic compounds on the same column — often under the same conditions.

To ensure reproducibility, we redeveloped our manufacturing process to maximize column-to-column consistency. Every Rxi® column is individually tested and proven to meet our stringent specifications for coating efficiency, selectivity, film thickness, inertness, and bleed. We guarantee every Rxi® column you receive will be the best column you have ever used.

**Under harsh operating conditions, choose stainless steel MXT® columns:**

- Rough handling (e.g., field instruments or process GC).
- Portable instruments / other small ovens requiring tightly coiled columns.
- High temperature chromatography.

When the potential for breakage is high, MXT® columns are your best choice — they present little risk of spontaneous breakage when used at high temperatures or when coiled into small diameters. While fused silica columns generally cannot be used above 360°C, because the polyimide outer coating becomes brittle over time at high temperatures, MXT® columns function well at temperatures exceeding 450°C. With an MXT® column, the only limitation to oven temperature is the operating limit of the stationary phase.

To prepare MXT® columns, we treat the internal surface of the stainless steel tubing with our exclusive Siltek® surface treatment, making the surface as inert as deactivated fused silica. The Siltek® layer permeates the surface, rather than simply coating it, making the layer

exceptionally flexible, so the tubing can be coiled to very small diameters. Coating efficiencies for MXT® columns are slightly lower than for fused silica columns, because the metal tubing has a larger surface area. We offer MXT® columns with a wide variety of stationary phases, in 0.18mm, 0.25mm, 0.32mm, and 0.53mm ID. The minimum coil diameter for 0.25mm ID or 0.53mm ID MXT® columns is 1.5 inches or 2.5 inches, respectively.

# Restek Capillary GC Column Selection Guide

## Stationary Phase

The stationary phase is the single most important consideration when you are choosing a column. The interactions between the analytes and the functional groups of the stationary phase contribute more to the overall results of the analysis than any other factor.

**Table 1** summarizes the characteristics, chemical structures and, broadly, suggested uses for Restek general-purpose stationary phases. Change selectivity by choosing a stationary phase with a different percentage of substitution of a particular functional group (e.g., by switching from a 5% diphenyl/95% dimethyl polysiloxane stationary phase to a 20% diphenyl/80% dimethyl polysiloxane stationary phase) or by choosing a stationary phase with different functional groups (e.g., by switching from a diphenyl/dimethyl polysiloxane stationary phase to a polyethylene glycol stationary phase). Note that a stationary phase's selectivity for sample components follows the general chemical principle of "like prefers like": a nonpolar stationary phase, such as the Rxi®-1 methyl polysiloxane stationary phase, will preferentially retain and separate nonpolar compounds, such as straight-chain hydrocarbons, relative to polar compounds, such as alcohols. As methyl groups are replaced with more polar functionalities, such as phenyl or cyanopropyl groups, selectivity shifts toward more polar compounds. Polar phases, such as polyethylene glycol phases (e.g., Stabilwax®), are highly selective toward alcohols or other polar compounds.

**Table 2** lists Restek special-purpose stationary phases. Columns with these phases are our first recommendations for the applications noted.

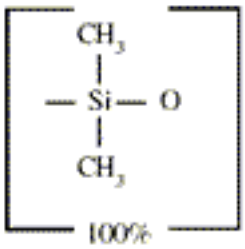
**Table 3** lists stationary phases we recommend for environmental analyses by US EPA methods.

**Table 4** lists retention indices for test compounds on the stationary phases characterized in Table 1. A retention index is a mathematical derivation indicating the elution position of a compound with respect to normal (straight chain) hydrocarbons. For example, a retention index of 650 for benzene on a particular stationary phase indicates benzene will elute mid-way between n-hexane (RI=600) and n-heptane (RI=700). The longer a particular compound is held by a stationary phase, the greater the retention index will be for that compound. Similarly, the greater the separation between two compounds, the greater the difference between their retention indices. To review retention indices for a wide variety of compounds on a range of Restek stationary phases, see the **retention index tables** in our on-line Expert Center.

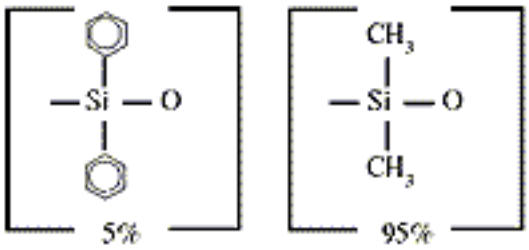
Note that if you will be using a selective detector, background levels in your chromatograms can be high if the stationary phase contains elements the detector is designed to respond to. For example, avoid using a cyanopropyl (CN)-containing stationary phase with a nitrogen-phosphorus detector, or a fluorine-containing stationary phase with an electron capture detector.

**Table 1** Stationary Phase Structures and Properties.

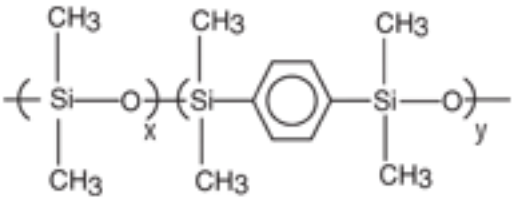
| Structure Diagram | Properties |
|---|---|



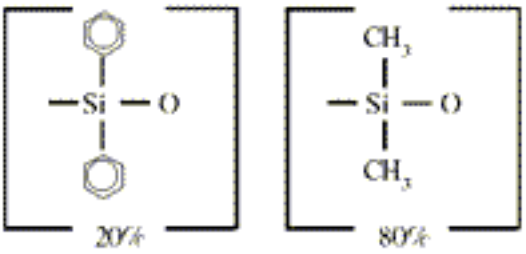

**Rxi®-1ms/Rtx®-1MS**
100% dimethyl polysiloxane
Stable to 360°C
Polarity: non-polar
Uses: solvents, petroleum products, pharmaceutical samples, waxes



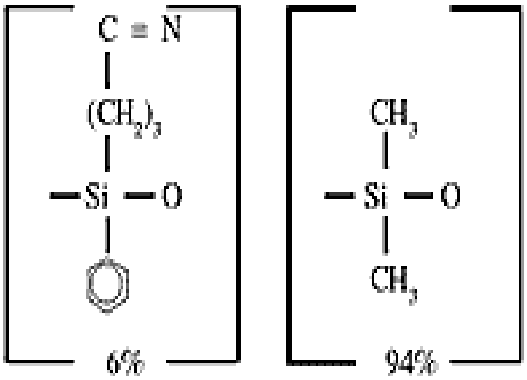

**Rxi®-5ms/Rtx®-5/Rtx®-5MS**
5% diphenyl - 95% dimethyl polysiloxane
Stable to 360°C
Polarity: slightly polar
Uses: flavors, environmental samples, aromatic hydrocarbons



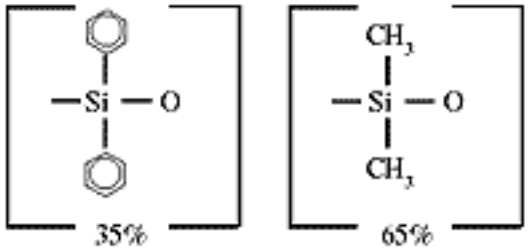

**Rxi®-5Sil MS/Rtx®-5Sil MS**
proprietary
Stable to 360°C
Polarity: slightly polar
Uses: flavors, environmental samples, pesticides, PCBs, aromatic hydrocarbons



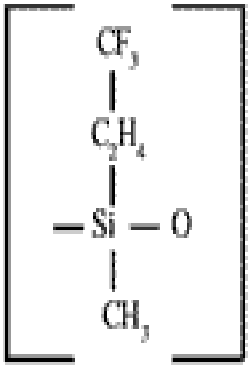

**Rtx®-20**
20% diphenyl - 80% dimethyl polysiloxane
Stable to 310°C
Polarity: slightly polar
Uses: volatile compounds, alcohols



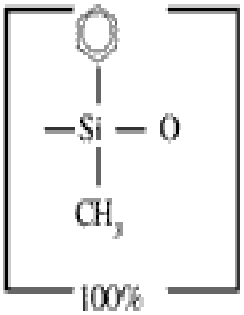

**Rtx®-1301, Rtx®-624**, **Rtx®-G43**
6% cyanopropylphenyl - 94% dimethyl polysiloxane
Stable to 280°C
Polarity: slightly polar
Uses: volatile compounds, insecticides, residue solvents in pharmaceutical products



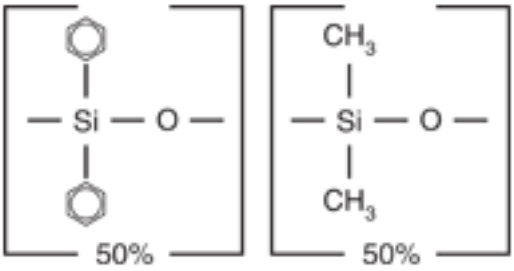

**Rtx®-35**
35% diphenyl - 65% dimethyl polysiloxane
Stable to 300°C
Polarity: intermediately polar
Uses: pesticides, Aroclor PCBs, amines, nitrogen-containing herbicides



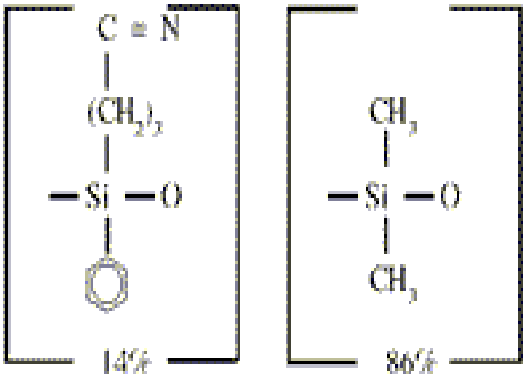

**Rtx®-200**
trifluoropropylmethyl polysiloxane
Stable to 360°C
Polarity: selective for lone pair electrons
Uses: environmental samples, solvents, Freon® gases, drugs, ketones, alcohols



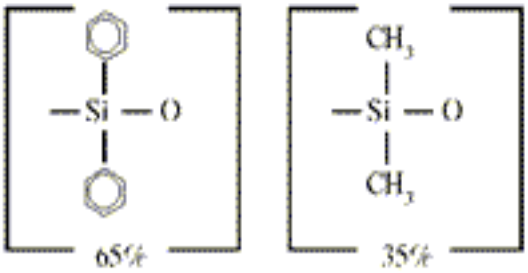

**Rtx®-50**
100% methylphenyl polysiloxane
Stable to 340°C
Polarity: intermediately polar
Uses: FAMEs, carbohydrates



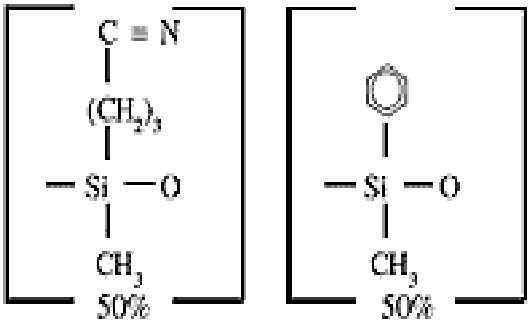

**Rxi®-17**
50% diphenyl - 50% dimethyl polysiloxane
Stable to 300°C
Polarity: intermediately polar
Uses: triglycerides, phthalate esters, steroids, phenols



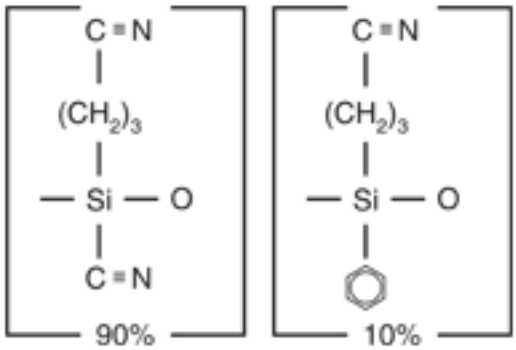

**Rtx®-1701**
14% cyanopropylphenyl - 86% dimethyl polysiloxane
Stable to 280°C
Polarity: intermediately polar
Uses: pesticides, Aroclor PCBs, alcohols, oxygenates



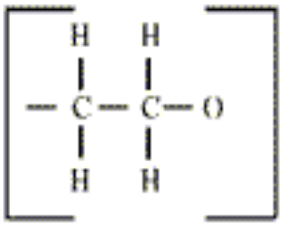

**Rtx®-65TG**
65% diphenyl - 35% dimethyl polysiloxane
Stable to 370°C
Polarity: intermediately polar
Uses: triglycerides, rosin acids, free fatty acids



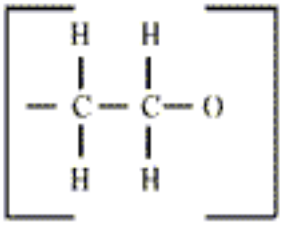
**Rtx®-225**
50% cyanopropylmethyl - 50% phenylmethyl polysiloxane
Stable to 260°C
Polarity: polar
Uses: FAMEs, carbohydrates



**Rt™-2330**
90% biscyanopropyl - 10% cyanopropylphenyl polysiloxane
Stable to 275°C
Polarity: very polar
Uses: *cis*/*trans* FAMEs, dioxin isomers, rosin acids



**Stabilwax®**
Carbowax® PEG
Stable to 250°C
Polarity: polar
Uses: FAMEs, flavors, acids, amines, solvents, xylene isomers



**Rtx®-Wax**
Carbowax® PEG
Stable to 250°C
Polarity: polar
Uses: FAMEs, solvents, BTEX aromatics, flavors

^ Back

**Table 2** Restek special-purpose stationary phases.

| Application | Stationary Phase |
|---|---|
| acids (underivatized) | Stabilwax®-DA |
| amines (underivatized); other basic compounds | Stabilwax®-DB |
| amines; other basic compounds | Rtx®-5 Amine<br>Rtx®-35 Amine |

| | |
|---|---|
| blood alcohol; glycols | Rtx®-BAC1<br>Rtx®-BAC2 |
| chiral compounds | Rt™-βDEX<br>Rt™-γDEX |
| detailed hydrocarbon analysis (ASTM/CGSB) | Rtx®-1PONA |
| dioxin and furan congeners | Rtx®-Dioxin<br>Rtx®-Dioxin2 |
| fatty acid methyl esters (FAMEs) | FAMEWAX |
| flavor and fragrance components | Rtx®-1 F&F<br>Rt™-CW20M F&F |
| nitroaromatic explosives<br>e.g.: US EPA method 8095 | Rtx®-TNT<br>Rtx®-TNT2 |
| organochlorine pesticides<br>e.g.: US EPA methods 8081, 608, CLP Pesticides | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Stx™-CLPesticides<br>Stx™-CLPesticides2 |
| organophosphorus pesticides<br>e.g.: US EPA method 8141A | Rtx®-OPPesticides<br>Rtx®-OPPesticides2 |
| PCB congeners | Rtx®-PCB<br>Stx™-500 |
| residual solvents in pharmaceuticals | Rtx®-G27<br>Rtx®-G43 |
| simulated distillation | MXT®-500 Sim Dist |
| simulated distillation: ASTM test method D2887 | Rtx®-2887 |
| volatile organic compounds<br>e.g.: US EPA methods 502.2, 524.2,601, 602, 624, 8010, 8020, 8260 | Rtx®-VGC<br>Rtx®-VMS<br>Rtx®-VRX<br>Rtx®-Volatiles<br>Rtx®-502.2<br>Rtx®-624 |

^ Back

**Table 3** Stationary phases we recommend for environmental analyses.
For example chromatograms, click on the name of the stationary phase.

| US EPA Method | Stationary Phase |
|---|---|
| 502.2 (volatile organics) | Rtx®-502.2 |
| 504.1 (dibromoethane/dibromochloropropane) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2 |
| 506 (phthalate & adipate esters) | Rxi®-5Sil MS/Rtx®-5Sil MS<br>Rxi®-1ms |
| 515/515.1 (chlorophenoxyacid herbicides) | Rtx®-440<br>Rtx®-50<br>Rtx®-CLPesticides<br>Rtx®-CLPesticides2 |
| 524.2, Rev. IV (volatile organics) | Rtx®-VMS |
| 525.2 (semivolatile organics) | Rxi®-5ms |
| 526 (semivolatile organics) | Rxi®-5Sil MS/Rtx®-5Sil MS |
| 528 (phenols) | Rxi®-5Sil MS/Rtx®-5Sil MS |
| 551.1 (chlorinated disinfection byproducts) | Rtx®-5<br>Rtx®-200<br>Rtx®-1301 |

| | |
|---|---|
| 552.2 (haloacetic acids) | Rtx®-5<br>Rtx®-200<br>Rtx®-CLPesticides<br>Rtx®-CLPesticides2 |
| 601 (volatile organics) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Stx™-CLPesticides<br>Stx™-CLPesticides2 |
| 602 (volatile organics) | Rtx®-VMS<br>Rtx®-VGC |
| 604 (phenols) | Rtx®-5<br>Rtx®-50<br>Rtx®-200 |
| 608 (organochlorine pesticides & PCBs) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Rtx®-PCB<br>Stx™-500 (PCBs) |
| 610 (polynuclear aromatic hydrocarbons) | Rxi®-5ms<br>Rxi®-5Sil MS/Rtx®-5Sil MS<br>Rtx®-440 |
| 615 (chlorophenoxyacid herbicides) | Rtx®-35<br>Rtx®-5 |
| 619 (organonitrogen/organophosphorus pesticides) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Rtx®-50<br>Rtx®-200 |
| 624 (volatile organics) | Rtx®-VMS, Rtx®-VGC |
| 1671 (volatile organics) | Stabilwax®<br>Stabilwax®-DB |
| 8010 (volatile organics) | Rtx®-VMS<br>Rtx®-VGC |
| 8020 (volatile organics) | Rtx®-VMS<br>Rtx®-VGC |
| 8021 (volatile organics) | Rtx®-VGC<br>Rtx®-VRX |
| 8081/8081A (organochlorine pesticides) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Stx™-CLPesticides<br>Stx™-CLPesticides2<br>Rtx®-440<br>Rtx®-XLB |
| 8095 (nitroaromatic explosives) | Rtx®-TNT<br>Rtx®-TNT2 |
| 8100 (polynuclear aromatic hydrocarbons) | Rtx®-5 |
| 8140/8141/8141A (organophosphorus pesticides) | Rtx®-OPPesticides<br>Rtx®-OPPesticides2<br>Rtx®-CLPesticides<br>Rtx®-CLPesticides2 |
| 8151/8151A (organochlorine pesticides) | Rtx®-CLPesticides<br>Rtx®-CLPesticides2<br>Rtx®-440 |
| 8240 (volatile organics) | Rtx®-VMS<br>Rtx®-VGC |
| 8260/8260B (volatile organics) | Rtx®-VMS |
| 8270/8270D (semivolatile organics) | Rxi®-5Sil MS/Rtx®-5Sil MS<br>Rxi®-5ms<br>Rtx®-XLB |
| Appendix IX (semivolatile organics) | Rxi®-5Sil MS/Rtx®-5Sil MS |
| CLP (semivolatile organics) | Rtx®-5ms |

| | |
|---|---|
| TO-14/TO-15 (air toxins) | Rtx®-1<br>Rtx®-502.2 |

^ Back

**Table 4** Retention indices for Restek general purpose stationary phases.

| Phase | Benzene | Butanol | Pentanone | Nitropropane |
|---|---|---|---|---|
| Rtx®-1 | 651 | 651 | 667 | 705 |
| Rtx®-5/Rtx®-5MS | 667 | 667 | 689 | 743 |
| Rtx®-20 | 711 | 704 | 740 | 820 |
| Rtx®-1301/Rtx®-624 | 689 | 729 | 739 | 816 |
| Rtx®-35 | 746 | 733 | 773 | 867 |
| Rtx®-200 | 738 | 758 | 884 | 980 |
| Rtx®-50 | 778 | 769 | 813 | 921 |
| Rtx®-1701 | 721 | 778 | 784 | 881 |
| Rtx®-65TG | 794 | 779 | 825 | 938 |
| Rtx®-225 | 847 | 937 | 958 | 958 |
| Stabilwax® | 963 | 1158 | 998 | 1230 |

^ Back



## CONTENTS



## ALSO OF INTEREST

# Restek Capillary GC Column Selection Guide

## Stationary Phase Film Thickness

Stationary phase film thickness affects the retention and elution temperature for each compound in the sample. A thicker film retains compounds longer, increasing the length of time each compound spends in the column (**Table 1** ). A thinner film retains compounds less, reducing the length of time each compound spends in the column. Very volatile compounds should be analyzed on a thick film column, to increase the time they spend in the column and allow them to separate. High molecular weight compounds must be analyzed on a thin film column, to reduce analysis time to a practical interval, and help minimize bleed at the higher temperatures required to elute such compounds.

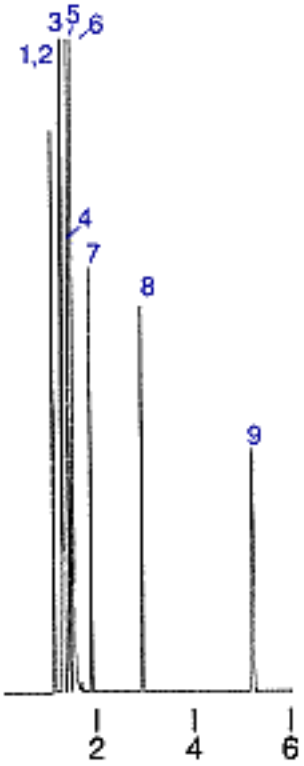
A comparative analysis of low boiling compounds on a 0.25µm, a 1.0µm, and a 5.0µm film of stationary phase, with all other variables held constant, shows the influence of film thickness (**Figure 1** ). The 0.25µm film does not resolve butanol from benzene (peaks 1 & 2). The 1.0µm film provides about 80% resolution of this pair, but retention times are more than double those for the 0.25µm film. The 5.0µm film does not improve resolution between butanol and benzene, relative to the 1.0µm film, and retention times are increased by a factor of six relative to the 0.25µm film. So, for this particular sample, the 1.0µm phase film is best: resolution is suitable for quantifying the analytes, analysis time is acceptable, and a thicker film does not offer notable improvements. On the other hand, if we wanted to resolve very volatile C2 or C3

compounds, which would elute prior to peak 1, the 5.0µm film would be required.

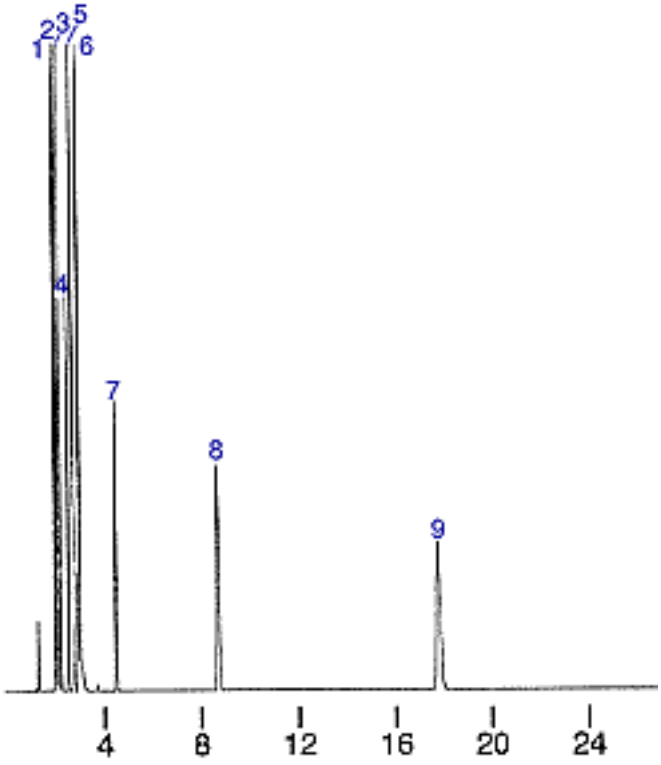
Both sample capacity and bleed increase as stationary phase film thickness is increased.

Changes in the column ID/stationary phase film thickness ratio, ß, are an important consideration when you want to make a change in column internal diameter or in stationary phase film thickness. Analyte retention increases as column internal diameter is decreased, and analyte retention decreases as stationary phase film thickness is decreased. When other column parameters and analysis conditions are held constant, a column with a smaller ß value will be more retentive for a given analyte. To assure similar retention and resolution when you increase the column ID, you also must increase the stationary phase film thickness. Similarly, if you wish to reduce the column ID, but keep retention and resolution similar, you also must reduce the stationary phase film thickness. **Table 2** lists ß values for common combinations of column ID and stationary phase film thickness; where ß values for different combinations are similar, elution patterns will be similar. To find ß values for other column ID/stationary phase film combinations, use the **Beta Calculator**.

**Figure 1** A sample containing low boiling components shows the differences in resolution among 0.25, 1.0, and 5.0µm columns. The 1.0µm column offers better resolution than the 0.25µm column, and the 5.0µm column does not offer any further improvements for compounds eluting after C6.

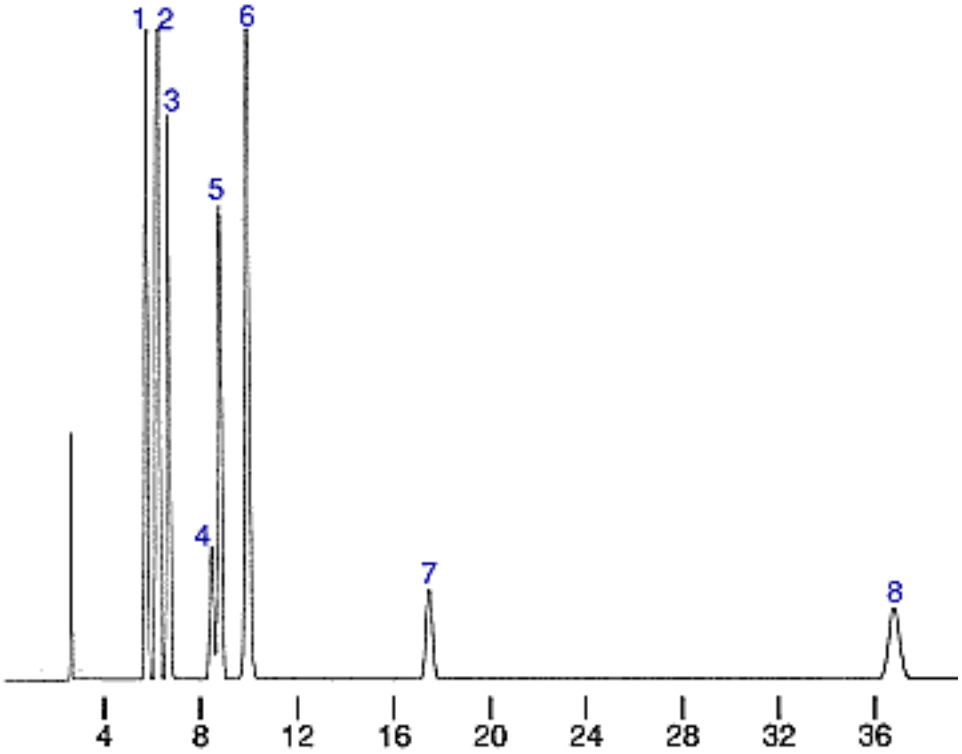



0.25µm, Rtx®-1




1.0µm, Rtx®-1

5.0µm, Rtx®-1




1. butanol
2. benzene
3. 2-pentanone
4. C7
5. 1-nitropropane
6. pyridine
7. C8
8. C9
9. C10

(Peak 9 elutes @ 117 minutes on the 5.0µm)

^ Back

**Table 1** Characteristics of thick film and thin film stationary phases.

| Thick Films | Thin Films |
|---|---|
| higher sample capacity | lower sample capacity |
| less efficient | more efficient |
| longer retention times | shorter retention times |
| effectively retain lower molecular weight analytes | efficiently release higher molecular weight analytes |
| higher bleed | lower bleed |

^ Back

**Table 2** Column ID: phase film ratio (ß) value calculation for film thickness vs. column IDs

| | phase film thickness (df) / ß value | | | | | | |
|---|---|---|---|---|---|---|---|
| Column ID | 0.10µm | 0.25µm | 0.50µm | 1.00µm | 1.50µm | 3.00µm | 5.00µm |
| 0.18mm | 450 | 180 | 90 | 45 | 30 | 15 | 9 |
| 0.25mm | 625 | 250 | 125 | 63 | 42 | 21 | 13 |
| 0.32mm | 800 | 320 | 160 | 80 | 53 | 27 | 16 |
| 0.53mm | 1325 | 530 | 265 | 128 | 88 | 43 | 27 |

^ Back



## CONTENTS



## ALSO OF INTEREST

# Restek Capillary GC Column Selection Guide

## Column Internal Diameter (ID)

Your need for **resolution**, the **concentrations of analytes** you anticipate in your samples, and the **sample introduction and analyte detection** instrumentation you are using will influence your choice of column internal diameter.

When all other column parameters and analysis conditions are held constant, analyte retention increases, and resolution improves, as column internal diameter is decreased. Sample capacity increases as internal diameter is increased. Bleed also increases as column diameter is increased and film thickness is held constant, because there is more stationary phase in the column, however for most applications the difference in bleed will be insignificant.

Columns with an ID of 0.25mm or less offer the highest column efficiencies, and therefore the greatest resolution, but have limited sample capacities, relative to wider ID columns. If concentrations of analytes in your samples exceed the capacity of the column, the analysis will be characterized by peak distortion, poor resolution, and poor reproducibility. For many applications a 0.32mm ID column offers the best balance of resolution and sample capacity.

0.53mm ID columns are best for high flow situations, such as accommodating incoming samples

from a purge and trap unit. Alternatively, columns with an ID of 0.25mm or less are the best choice for GC/MS applications — they provide optimal performance with small flows of carrier gas, and thus can be connected directly to the vacuum source of a mass spectrometer, eliminating the complications associated with a jet separator.

Use **Table 1** to compare typical column characteristics according to column ID, then select the ID that best matches your needs.

**Table 1** Characteristics of thick film and thin film stationary phases.

**Select Column ID:**

Make a Selection

| Column Parameters |
| --- |
| Typical Spitless Purge Time |
| He split vent flow rate (50:1 split ratio) |
| H2 split vent flow rate (50:1 split ratio) |
| Column OD (Ferrule ID) |
| Column Flow Rate (He @ 20cm/sec.) |
| Column Flow Rate (H2 @ 40cm/sec.) |
| Approximate Sample Capacity |
| Typical Effective Plates/m (80% CE) |

| Approximate column head pressure (He or H2 carrier gas) | |
| --- | --- |
| Column (m): | 610121520253040607510 5150 |
| Head Pressure (psig): | |

Always optimize the column flow rate by using linear velocity.

## Phase Ratio Calculations

Changes in the column ID/stationary phase film thickness ratio, beta, are an important consideration when you want to make a change in column internal diameter or in stationary phase film thickness. Analyte retention increases as column internal diameter is decreased, and analyte retention decreases as stationary phase film thickness is decreased. When other column parameters and analysis conditions are held constant, a column with a smaller beta value will be more retentive for a given analyte. To assure similar retention and resolution when you increase

the column ID, you also must increase the stationary phase film thickness. Similarly, if you wish to reduce the column ID, but keep retention and resolution similar, you also must reduce the stationary phase film thickness. **Table 2** lists beta values for common combinations of column ID and stationary phase film thickness; where beta values for different combinations are similar, elution patterns will be similar. To find beta values for other column ID/stationary phase film combinations, use the **Beta Calculator**.

**Table 2** Column ID: phase film ratio (beta) values for commonly used column dimensions.

| | phase film thickness (df) / beta value | | | | | | |
|---|---|---|---|---|---|---|---|
| Column ID | 0.10µm | 0.25µm | 0.50µm | 1.00µm | 1.50µm | 3.00µm | 5.00µm |
| 0.18mm | 450 | 180 | 90 | 45 | 30 | 15 | 9 |
| 0.25mm | 625 | 250 | 125 | 63 | 42 | 21 | 13 |
| 0.32mm | 800 | 320 | 160 | 80 | 53 | 27 | 16 |
| 0.53mm | 1325 | 530 | 265 | 128 | 88 | 43 | 27 |



## CONTENTS



## ALSO OF INTEREST

SELECTION GUIDE

# Restek Capillary GC Column Selection Guide

## Column Length

Longer columns provide more resolving power, but increase analysis time and column purchase costs. As you consider whether the increase in resolution is worth the extra time and expense, remember that the benefit of using a longer column is much greater if you are performing a temperature programmed analysis than if you are performing an isothermal analysis. In an **isothermal analysis**, retention time varies directly with column length: if column length is doubled, analysis time will double as well. The increase in resolution will be only approximately 40%, however, because resolution is related to the square root of column length, as shown in the equation below. In a **temperature programmed analysis**, retention times are more dependent on temperature than on column length. As column length is increased, the increase in resolution will be the same as for an isothermal analysis, but there will be only a marginal increase in analysis time.

# Length Effects

Length affects resolution and speed of analysis.

$$\text{Resolution} = \frac{1}{4}\sqrt{\frac{L}{h}} \times \frac{k}{k+1} \times \frac{\alpha-1}{\alpha}$$

L = length  h = HETP  k = capacity factor  $\alpha$ = selectivity