Table II Optimal flow rates for various particle diameters and column internal diameters.

Column ID (mm)	Optimal flow rate (mL/min.)			
	1.9 µm dp	2.2 µm dp	3µm dp	5 µm dp
4.6			1.50	1.00
3.2			0.73	0.50
3.0	1.12	1.00	0.65	0.40
2.1	0.55	0.47	0.31	0.20
1.0			0.07	0.05

Table III Common classifications for LC columns by internal diameter.

Classification	Internal Diameter
Capillary	<1.0 mm ID
Micro bore	1.0 mm ID
Narrow bore	2.1-3.0 mm ID
Standard bore	3.2-4.6 mm ID
Semi-prep	10 to 21.2 mm ID
Prep	30 to 50 mm ID

System volume, or extra column volume, also affects efficiency. As extra column volume increases, lower efficiency is experienced as band broadening increases. Typically, column IDs less than 3.0 mm, considered narrow bore columns, require systems with minimized extra column volume. Table III defines the classification of columns according to internal diameter or bore. Another contributor to overall system volume and column ID choice is the system delay volume. Delay volume is the volume contained between the pumps and the column, often including the mixing chamber and injection valve. Delay volume is especially significant during gradient analysis. Narrow bore columns often require lower flow rates, and these lower flow rates will not sweep the delay volume in high volume systems quickly. This extends analysis time and creates an increased gradient lag time. For fast gradient analysis and LC/MS, narrow bore columns and systems with low extra column volume are recommended.

Physical Characteristics

Silica Type

The physical characteristics of the support material can be selected to control retention and peak shape. The base silica, commonly porous spherical particles, used in the manufacturing of the column can first be selected by type, namely Type A, Type B, or Base Deactivated. Type B silica is typically higher in purity and provides limited silanol activity. When analyzing basic compounds, especially without the use of mobile phase modifiers, Type B silica is recommended for more symmetric peak shape. Type A and Base Deactivated silica are recommended for acidic, neutral, and slightly basic compounds.

Another criterion for choosing a column line is the porosity of the silica. The pore size, or pore diameter, which is commonly expressed in Å, is the average diameter of the silica pores. This relates inversely to available surface area. Smaller pore volumes create a larger surface area in a given particle and, therefore, can be used to control the amount of stationary phase bonded to the particle.

The carbon load, or % carbon in the packing material, is the measure of the amount, or load, of stationary phase. Carbon load directly affects retention. Higher carbon loads typically result in higher retention characteristics. Figure 1 illustrates the relative retention capacities of commercially available columns for hydrophobic compounds. Allure® columns were designed for maximum retention of small molecules by utilizing high carbon load, surface area, and ligand density. In contrast, Viva columns, considered wide pore, have a large pore diameter and are used for the analysis of larger molecules as commonly seen in biological separations. Table IV summarizes the physical characteristics and recommended uses for Restek column lines.

Silica columns commonly have a temperature limit of 80 °C. Increased temperature can be used to decrease mobile phase viscosity and, therefore, lower the back pressure of a

Table IV Physical characteristics and recommended uses for Restek columns, based on silica lines.

Column Line	Pore Size (Å)	Surface Area (m^2/g)	Carbon Load Range* (%)	Usage
Allure	60	450	12–27	Very high retention (highest retention available) High purity 5 µm particle size only
Ultra II	100	300	11–19	High retention High purity Full range particle size - 1.9, 2.2, 3 and 5 µm for UHPLC and HPLC
Ultra	100	300	2–20	High retention High purity 3 and 5 µm particle size only
Pinnacle II	110	180	2–13	Moderate retention Acidic Type A (not for RP analyses of bases) 3 and 5 µm particle size only
Pinnacle DB	140	150	4–11	Moderate retention Base deactivated silica 1.9, 3 and 5 µm particle sizes
Viva	300	100	3.5–9	Low retention Wide-pore silica for biological separations

*Ranges are based on phases available for each silica line. See column product listings for more specific information.