G-20 CHROMATOGRAPHY

INTRODUCTION

Chromatographic separation techniques are multi-stage separation methods in which the components of a sample are distributed between 2 phases, one of which is stationary, while the other is mobile. The stationary phase may be a solid or a liquid supported on a solid or a gel. The stationary phase may be packed in a column, spread as a layer, or distributed as a film, etc. The mobile phase may be gaseous or liquid or supercritical fluid. The separation may be based on adsorption, mass distribution (partition), ion exchange, etc., or may be based on differences in the physico-chemical properties of the molecules such as size, mass, volume, etc.

This chapter contains definitions and calculations of common parameters and generally applicable requirements for system suitability. Principles of separation, apparatus and methods are given in the corresponding general chapters.

DEFINITIONS

The system suitability and acceptance criteria in monographs have been set using parameters as defined below. With some equipment, certain parameters, such as the signal-to-noise ratio and resolution, can be calculated using software provided by the manufacturer. It is the responsibility of the user to ensure that the calculation methods used in the software are equivalent to the requirements of the <Name> Pharmacopoeia and to make any necessary corrections if this is not the case.

Chromatogram

A graphical or other representation of detector response, effluent concentration or other quantity used as a measure of effluent concentration, versus time or volume. Idealised chromatograms are represented as a sequence of Gaussian peaks on a baseline (Figure 1).

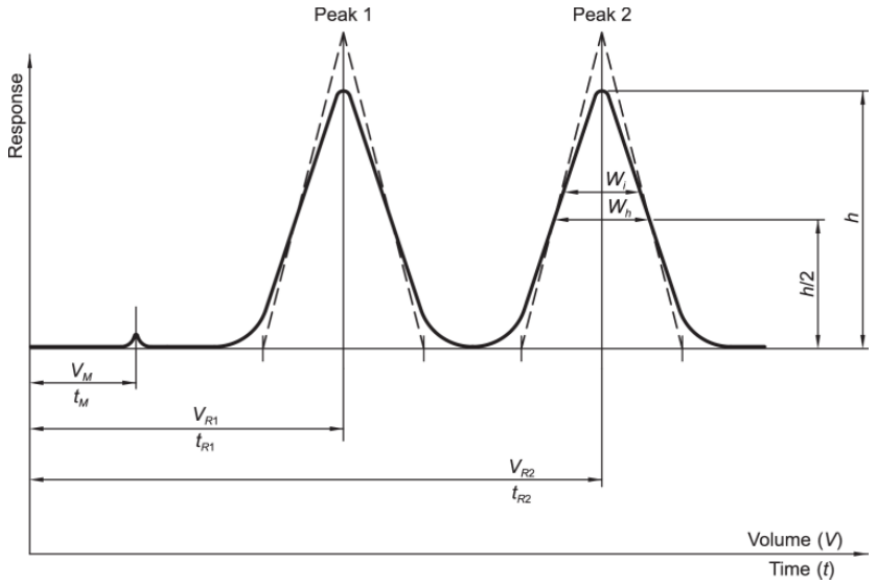


Figure 1

V_M = hold-up volume;
t_M = hold-up time;
V_{R1} = retention volume of peak 1;
t_{R1} = retention time of peak 1;

V_{R2} = retention volume of peak 2;
t_{R2} = retention time of peak 2;
W_h = peak width at half-height;
W_i = peak width at the inflexion point;
h = height of the peak;
h/2 = half-height of peak.

Distribution constant (K_0)

In size-exclusion chromatography, the elution characteristics of a component in a particular column may be given by the distribution constant (also referred to as distribution coefficient), which is calculated using the following equation:

$$K_0 = \frac{t_R - t_0}{t_t - t_0}$$

t_R = retention time;
t_0 = retention time of an unretained compound;
t_t = total mobile phase time.

Dwell volume (D) (also referred to as V_D):

The dwell volume (also known as gradient delay volume) is the volume between the point at which the eluents meet and the inlet of the column. It can be determined using the following procedure.

Column: replace the chromatographic column by an appropriate capillary tubing (e.g. 1 m × 0.12 mm).

Mobile phase:
− *mobile phase A*: *water*;
− *mobile phase B*: 0.1 per cent *V/V* solution of *aceto*ne in *water*;

Time (min)	Mobile phase A (per cent *V/V*)	Mobile phase B (per cent *V/V*)
0 – 20	100 → 0	0 → 100
20 - 30	0	100

Flow rate: set to obtain sufficient back-pressure (e.g. 2 mL/min).

Detection: spectrophotometer at 265 nm.

Determine the time ($t_{0.5}$) in minutes when the absorbance has increased by 50 per cent (Figure 2).

$$D = t_D \times F$$

$t_D = t_{0.5} - 0.5t_G$, in minutes;
t_G = pre-defined gradient time (= 20 min);
F = flow rate, in millilitres per minute.

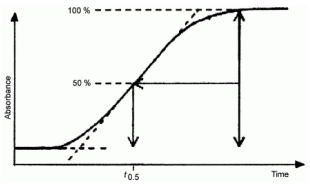


Figure 2

Note: where applicable, this measurement is performed with the autosampler in the *inject* position so as to include the injection loop volume in the dwell volume.

Hold-up time (t_M)

Time required for elution of an unretained component (Figure 1, baseline scale being in minutes or seconds).

In size-exclusion chromatography, the term retention time of an unretained compound (t_0) is used.

Hold-up volume (V_M)

Volume of the mobile phase required for elution of an unretained component. It may be calculated from the hold-up time and the flow rate (F) in millilitres per minute using the following equation:

$$V_M = t_M \times F$$

In size-exclusion chromatography, the term retention volume of an unretained compound (V_0) is used.

Peak

Portion of a chromatogram recording the detector response when a single component (or 2 or more unresolved components) is eluted from the column.

The peak response may be represented by the peak area or the peak height (h).

Peak-to-valley ratio (p/v)

The peak-to-valley ratio may be employed as a system suitability criterion when baseline separation between two peaks is not achieved (Figure 3).

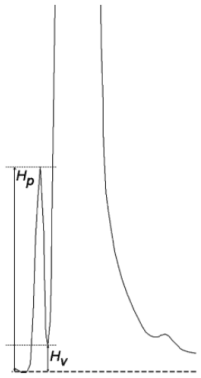


Figure 3

$$p/v = \frac{H_p}{H_v}$$

H_p = height above the extrapolated baseline of the minor peak;

H_v = height above the extrapolated baseline at the lowest point of the curve separating the minor and major peaks.

Plate height (*H*) (synonym: Height equivalent to one theoretical plate (HETP))
Ratio of the column length (*L*), in micrometers, to the plate number (*N*):

$$H = \frac{L}{N}$$

Plate number (*N*) (synonym: Number of theoretical plates)
The column performance (efficiency) may be calculated from data obtained under either isothermal, isocratic or isodense conditions, depending on the technique, as the plate number, using the following equation, the values of t_R and w_h being expressed in the same units:

$$N = 5.54\left(\frac{t_R}{w_h}\right)^2$$

t_R = retention time of the peak corresponding to the component;
w_h = peak width at half-height (h/2).

The plate number varies with the component as well as with the column, the column temperature, the mobile phase and the retention time.

Reduced plate height (*h*)
Ratio of the plate height (*H*), in micrometers, to the particle diameter (d_p) in micrometers:

$$h = \frac{H}{d_p}$$

Relative retardation (*R rel*)
The relative retardation, used in thin-layer chromatography, is calculated as the ratio of the distances travelled by the spot of the compound of interest and a reference compound (Figure 4).

$$R\ rel = b/c$$

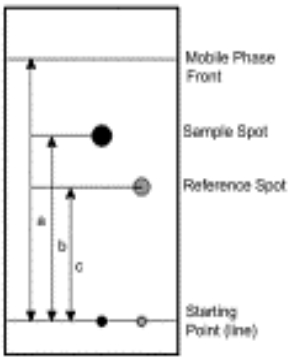


Figure 4

Relative retention (*r*)
Relative retention is calculated as an estimate using the following equation:

$$r = \frac{t_{Ri} - t_M}{t_{Rst} - t_M}$$

t_{Ri} = retention time of the peak of interest;
t_{Rst} = retention time of the reference peak (usually the peak corresponding to the substance to be examined);
t_M = hold-up time.

The unadjusted relative retention (r_G) [synonym in USP: relative retention time (RRT)] is calculated using the following equation:

$$r_G = \frac{t_{Ri}}{t_{Rst}}$$

Unless otherwise indicated, values for relative retention stated in monographs correspond to unadjusted relative retention.

Resolution (R_s)

The resolution between peaks of 2 components (Figure 1) may be calculated using the following equation:

$$R_s = \frac{1.18(t_{R2} - t_{R1})}{w_{h1} + w_{h2}}$$

$t_{R2} > t_{R1}$
t_{R1}, t_{R2} = retention times of the peaks;
w_{h1}, w_{h2} = peak widths at half-height.

In quantitative thin-layer chromatography, using densitometry, the migration distances are used instead of retention times and the resolution between peaks of 2 components may be calculated using the following equation:

$$R_s = \frac{1.18a(R_{F2} - R_{F1})}{w_{h1} + w_{h2}}$$

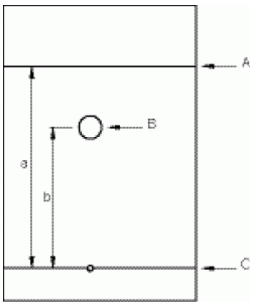
$R_{F2} > R_{F1}$
R_{F1}, R_{F2} = retardation factors of the peaks;
w_{h1}, w_{h2} = peak widths at half-height;
a = migration distance of the solvent front.

Retardation factor (R_F)

The retardation factor (also known as retention factor (R_f)), used in thin-layer chromatography, is the ratio of the distance from the point of application to the centre of the spot and the distance simultaneously travelled by the solvent front from the point of application (Figure 5).

$$R_F = \frac{b}{a}$$

b = migration distance of the component;
a = migration distance of the solvent front.



A. mobile phase front *B. spot* *C. line of application*

Figure 5

Retention factor (*k*)

The retention factor (also known as mass distribution ratio (D_m) or capacity factor (k')) is defined as:

$$k = \frac{\text{amount of component in stationary phase}}{\text{amount of component in mobile phase}} = K_C \frac{V_s}{V_M}$$

K_C = distribution constant (also known as equilibrium distribution coefficient);
V_S = volume of the stationary phase;
V_M = volume of the mobile phase.

The retention factor of a component may be determined from the chromatogram using the following equation:

$$k = \frac{t_R - t_M}{t_M}$$

t_R = retention time;
t_M = hold-up time.

Retention time (t_R)

Time elapsed between the injection of the sample and the appearance of the maximum peak response of the eluted sample zone (Figure 1, baseline scale being in minutes or seconds).

Retention volume (V_R)

Volume of the mobile phase required for elution of a component. It may be calculated from the retention time and the flow rate (F) in millilitres per minute using the following equation:

$$V_R = t_R \times F$$

Retention time of an unretained compound (t_0)

In size-exclusion chromatography, retention time of a component whose molecules are larger than the largest gel pores (Figure 6).

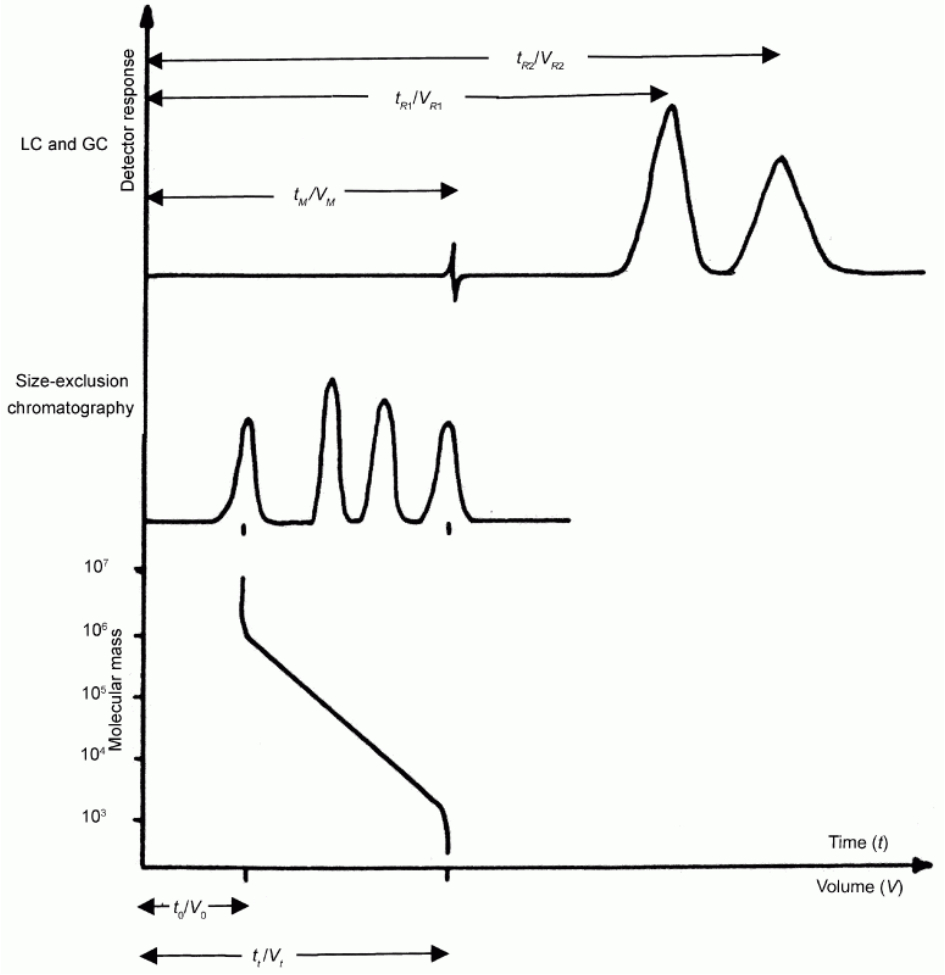


Figure 6

Retention volume of an unretained compound (V_0)

In size-exclusion chromatography, retention volume of a component whose molecules are larger than the largest gel pores. It may be calculated from the retention time of an unretained compound and the flow rate (F) in millilitres per minute using the following equation:

$$V_0 = t_0 \times F$$

Separation factor (α)

Relative retention calculated for two adjacent peaks (by convention, the value of the separation factor is always > 1):

$$\alpha = k_2/k_1$$

k_1 = retention factor of the first peak;
k_2 = retention factor of the second peak.

Signal-to-noise ratio (S/N)

The short-term noise influences the precision and accuracy of quantification. The signal-to-noise ratio is calculated using the following equation:

$$S/N = \frac{2H}{h}$$

H = height of the peak (Figure 7) corresponding to the component concerned, in the chromatogram obtained with the prescribed reference solution, measured from

the maximum of the peak to the extrapolated baseline of the signal observed over a distance equal to 20 times the width at half-height;

h = range of the noise in a chromatogram obtained after injection of a blank (Figure 8), observed over a distance equal to 20 times the width at half-height of the peak in the chromatogram obtained with the prescribed reference solution and, if possible, situated equally around the place where this peak would be found.

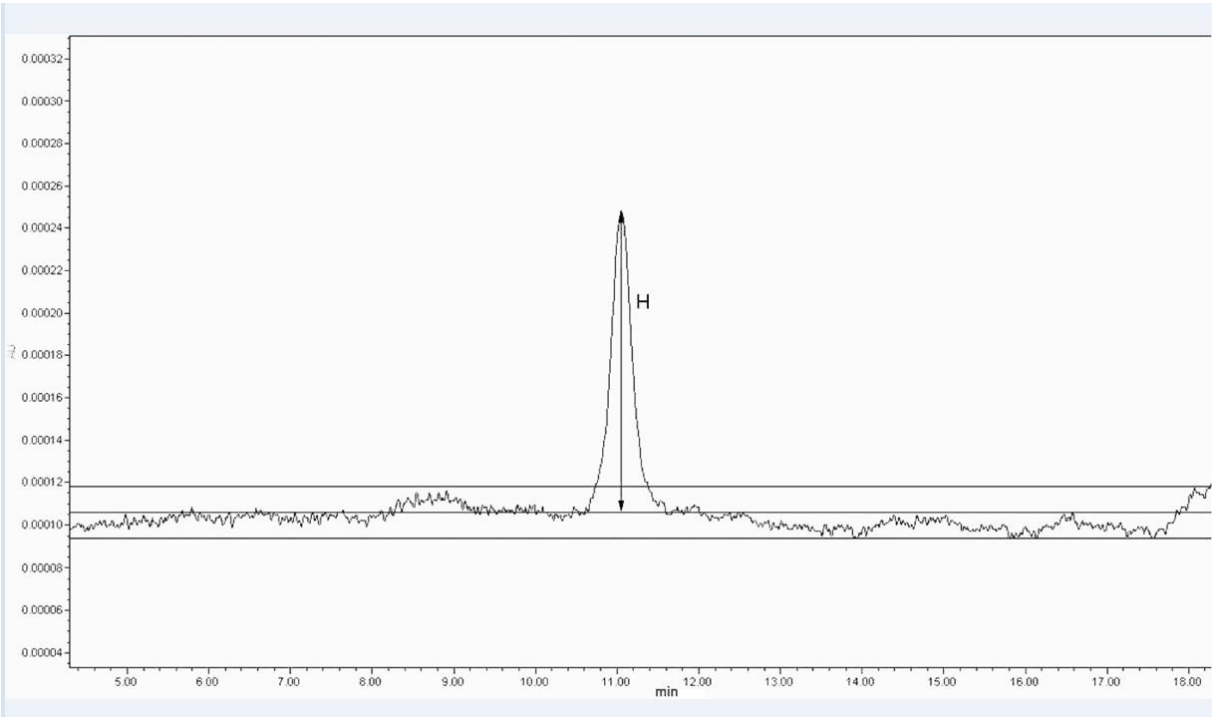


Figure 7. Chromatogram of the reference solution

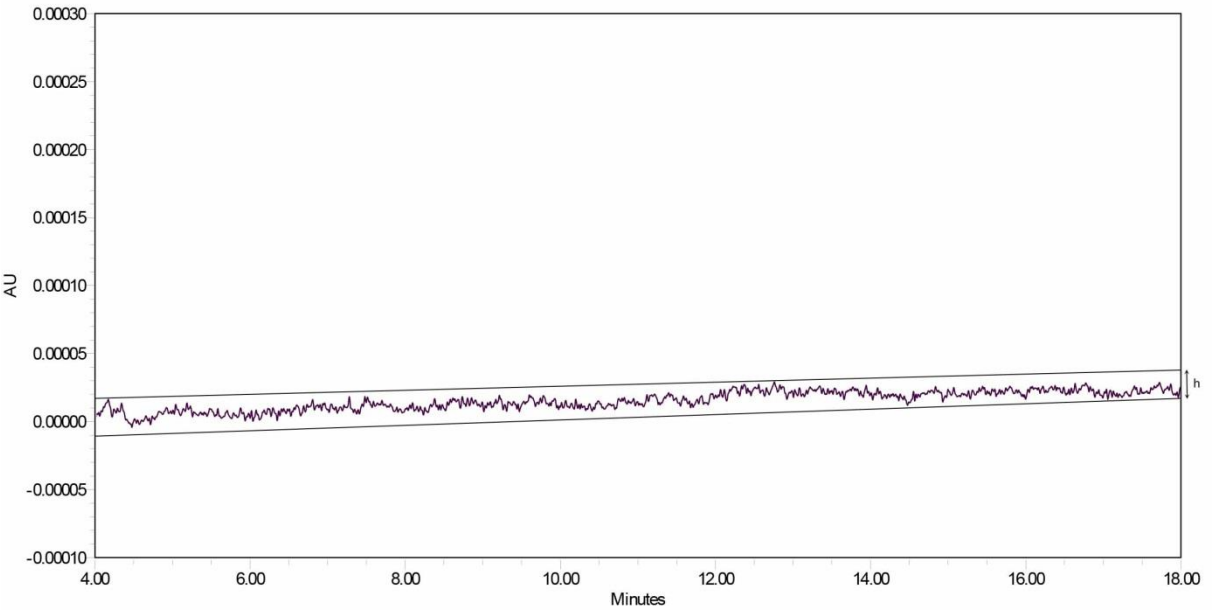


Figure 8. Chromatogram of a blank

If a baseline of 20 times the width at half-height is not obtainable because of peaks due to the solvents or reagents, or arising from the mobile phase or the sample matrix, a baseline of at least 5 times the width at half-height is permitted.

Symmetry factor (A_s)

The symmetry factor of a peak (also known as the asymmetry factor or tailing factor) (Figure 9) is calculated using the following equation:

$$A_s = \frac{w_{0.05}}{2d}$$

$w_{0.05}$ = width of the peak at one-twentieth of the peak height;
d = distance between the perpendicular dropped from the peak maximum and the leading edge of the peak at one-twentieth of the peak height.

An A_s value of 1.0 signifies symmetry. When $A_s > 1.0$, the peak is tailing. When $A_s < 1.0$, the peak is fronting.

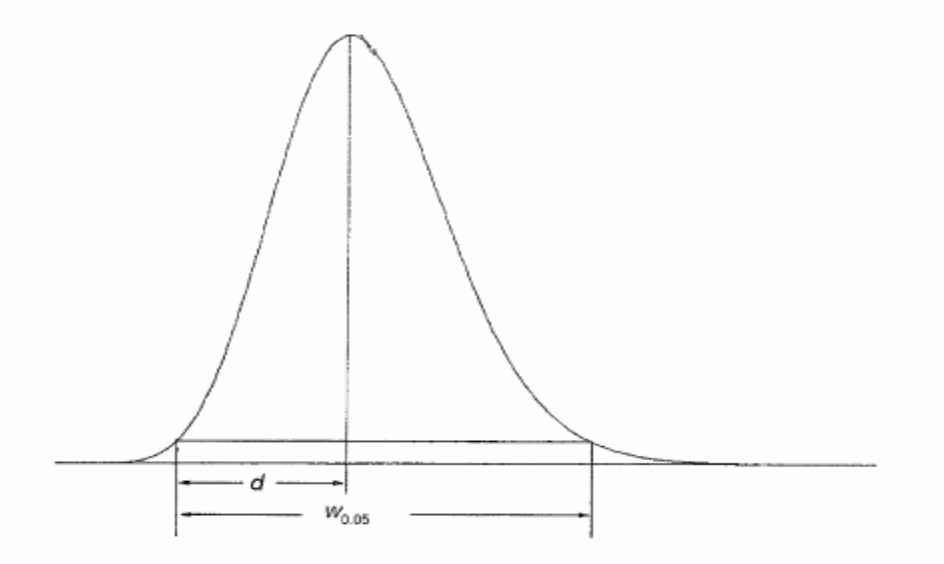


Figure 9

System repeatability

The repeatability of response is expressed as an estimated percentage relative standard deviation (%RSD) of a consecutive series of measurements for not fewer than 3 injections or applications of a reference solution, and is calculated using the following equation:

$$\%\text{RSD} = \frac{100}{\bar{y}} \sqrt{\frac{\sum(y_i - \bar{y})^2}{n-1}}$$

y_i = individual values expressed as peak area, peak height, or ratio of areas by the internal standardisation method;
$\bar{y}$ = mean of individual values;
n = number of individual values.

Total mobile phase time (t_t)
In size-exclusion chromatography, retention time of a component whose molecules are smaller than the smallest gel pores (Figure 6).

Total mobile phase volume (V_t)
In size-exclusion chromatography, retention volume of a component whose molecules are smaller than the smallest gel pores. It may be calculated from the total mobile phase time and the flow rate (F) in millilitres per minute using the following equation:

$$V_t = t_t \times F$$

SYSTEM SUITABILITY

This section only covers liquid chromatography and gas chromatography.

The various components of the equipment employed must be qualified and be capable of achieving the performance required to conduct the test or assay.
The system suitability tests represent an integral part of the method and are used to ensure adequate performance of the chromatographic system. Apparent efficiency, retention factor (mass distribution ratio), resolution and symmetry factor are the parameters that are usually employed in assessing the performance of the chromatographic system. Factors that may affect the chromatographic behaviour include:
- the composition, ionic strength, temperature and apparent pH of the mobile phase;
- flow rate, column dimensions, column temperature and pressure;
- stationary phase characteristics including type of chromatographic support (particle-based or monolithic), particle or macropore size, porosity, specific surface area;
- reversed phase and other surface-modification of the stationary phases, the extent of chemical modification (as expressed by end-capping, carbon loading etc.).

Retention times and relative retentions may be provided in monographs for informational purposes. There are no acceptance criteria applied to relative retentions.

Compliance with the system suitability criteria is required throughout the chromatographic procedure. No sample analysis is acceptable unless the suitability of the system has been demonstrated.

Unless otherwise prescribed in the individual monograph, the following requirements are to be fulfilled:

- ***System repeatability – assay of an active substance or an excipient***

In an assay of an active substance or an excipient, where the target value is 100 per cent for a pure substance, and a system repeatability requirement is not specified, the maximum permitted relative standard deviation (%RSD_{max}) for the defined limits is calculated for a series (n = 3 to 6) of injections of the reference solution. The maximum permitted relative standard deviation of the peak response does not exceed the appropriate value given in Table 1.

Table 1 – System repeatability requirements (assay)

	Number of individual injections *n*			
	3	4	5	6
B (per cent)	*Maximum permitted relative standard deviation (per cent)*			
2.0	0.41	0.59	0.73	0.85
2.5	0.52	0.74	0.92	1.06
3.0	0.62	0.89	1.10	1.27

B = upper limit of content given in the individual monograph minus 100 per cent.

- ***Sensitivity***

The sensitivity is the signal output per unit concentration or unit mass of the substance in the mobile phase entering the detector. In related substances tests, the signal-to-noise ratio is used to define the sensitivity. Unless otherwise stated, at the reporting threshold, a signal-to-noise ratio equal to or greater than 10 must be achieved.

- ***Peak symmetry***

Unless otherwise stated, in a test or assay, the symmetry factor (tailing factor) of the peak used for quantification is 0.8 to 1.8.

ADJUSTMENT OF CHROMATOGRAPHIC CONDITIONS

The chromatographic conditions described have been validated during the elaboration of the monograph.
The extent to which the various parameters of a chromatographic test may be adjusted to satisfy the system suitability criteria without fundamentally modifying the methods are listed below. Changes other than those indicated require revalidation of the method.

The system suitability tests are included to verify that conditions required for satisfactory performance of the test or assay are achieved. Nonetheless, since the stationary phases are described in a general way and there is such a variety available commercially, with differences in chromatographic behaviour, some adjustments of the chromatographic conditions may be necessary to achieve the prescribed system suitability requirements. With reversed-phase liquid chromatographic methods in particular, adjustment of the various parameters will not always result in satisfactory chromatography. In that case, it may be necessary to replace the column with another of the same type (e.g. octadecylsilyl silica gel), which exhibits the desired chromatographic behaviour.

Adjustment of conditions with gradient elution is more critical than with isocratic elution, since it may shift some peaks to a different step of the gradient, thus leading to the incorrect assignment of peaks, and to the masking of peaks or a shift such that elution occurs beyond the prescribed elution time.
For critical parameters the adjustments are explicitly defined in the monograph to ensure the system suitability.

Thin-layer chromatography

Composition of the mobile phase: the amount of the minor solvent component may be adjusted by ± 30 per cent relative or ± 2 per cent absolute, whichever is the larger; for a minor component at 10 per cent of the mobile phase, a 30 per cent relative adjustment allows a range of 7-13 per cent whereas a 2 per cent absolute adjustment allows a range of 8-12 per cent, the relative value therefore being the larger; for a minor component at 5 per cent of the mobile phase, a 30 per cent relative adjustment allows a range of 3.5-6.5 per cent whereas a 2 per cent absolute adjustment allows a range of 3-7 per cent, the absolute value being the larger in this case.

pH of the aqueous component of the mobile phase: ± 0.2 pH units, unless otherwise prescribed, or ± 1.0 pH unit when non-ionisable substances are to be examined.

Concentration of salts in the buffer component of a mobile phase: ± 10 per cent.

Application volume: 10-20 per cent of the prescribed volume if using fine particle size plates (2-10 µm).

Liquid chromatography: isocratic elution

Column parameters and flow rate

- *Stationary phase*: no change of the physico-chemical characteristics of the stationary phase permitted, i.e. chromatographic support, surface modification and extent of chemical modification must be the same; a change from Totally Porous Particle (TPP) columns to Superficially Porous Particle (SPP) columns is allowed provided these requirements are met.

- *Column dimensions*: the particle size and/or length of the column may be modified provided that the ratio of the column length (*L*) to the particle size (*dp*) remains constant or in the range between − 25 per cent to + 50 per cent of the prescribed *L*/*dp* ratio. For the application of particle-size adjustment to superficially porous particles, other combinations of *L* and *dp* can be used provided that the number of theoretical plates (*N*) is within – 25 per cent to + 50 per cent, relative to the prescribed column. These changes are acceptable provided system suitability requirements are fulfilled, and selectivity and elution order of the specified impurities to be controlled are demonstrated to be equivalent. Further adjustments in method conditions (mobile phase, temperature, pH, etc.) may be required, within the permitted ranges described under System Suitability and Adjustment of chromatographic conditions in this chapter.

Caution is necessary when the adjustment results in a higher number of theoretical plates generating smaller peak volumes, a situation which may require adjustments to minimize extra-column band broadening by factors such as instrument connections, detector cell volume and sampling rate, and injection volume.

When the particle size is changed, the flow rate may require adjustment, because smaller-particle columns will require higher linear velocities for the same performance (as measured by reduced plate height). The flow rate is adjusted for both the change in column diameter and particle size using the following equation:

$$F_2 = F_1 \times [(dc_2^2 \times dp_1)/(dc_1^2 \times dp_2)]$$

F_1 = flow rate indicated in the monograph, in millilitres per minute;
F_2 = adjusted flow rate, in millilitres per minute;
dc_1 = internal diameter of the column indicated in the monograph, in millimetres;
dc_2 = internal diameter of the column used, in millimetres;
dp_1 = particle size indicated in the monograph, in micrometres;
dp_2 = particle size of the column used, in micrometres.

When a change is made from ≥ 3-µm to < 3-µm particles in isocratic separations, an additional increase in linear velocity (by adjusting the flow rate) may be justified, provided that the column efficiency does not drop by more than 20 per cent. Similarly, a change from < 3-µm to ≥ 3-µm particles may require additional reduction of linear velocity (flow rate) to avoid reduction in column efficiency by more than 20 per cent.

After an adjustment due to a change in column dimensions, an additional change in flow rate of ± 50 per cent is permitted.

- *Temperature*: ± 10 °C, where the operating temperature is specified, unless otherwise prescribed.

Mobile phase

- *Composition*: the amount of the minor solvent component may be adjusted by ± 30 per cent relative or ± 2 per cent absolute, whichever is the larger (see example above). A minor component comprises less than (100/*n*) per cent, *n* being the total number of components of the mobile phase;
- *pH of the aqueous component of the mobile phase*: ± 0.2 pH units, unless otherwise prescribed;
- *Concentration of salts in the buffer component of a mobile phase*: ± 10 per cent.

Detector wavelength: no adjustment permitted.

Injection volume: except for changes from TPP columns to SPP columns, when the column dimensions are changed, injection volume adjustment may be guided by:

$$V_{inj2} = V_{inj1} (L_2 \, d_{c2}^2) / (L_1 \, d_{c1}^2)$$

V_{inj1} = injection volume indicated in the monograph, in microlitres;
V_{inj2} = adjusted injection volume, in microlitres;
L_1 = column length indicated in the monograph, in millimetres;
L_2 = new column length, in millimetres;
d_{c1} = column internal diameter indicated in the monograph, in millimetres;
d_{c2} = new column internal diameter, in millimetres.

Even in the absence of any column dimension change, the injection volume may be varied provided System Suitability criteria remain within their established acceptability limits. When the injection volume is decreased, special attention is given to (limit of) detection and repeatability of the peak response(s) to be determined. An increase is permitted provided, in particular, linearity and resolution of the peak(s) to be determined remain satisfactory.

Liquid chromatography: gradient elution

Adjustment of chromatographic conditions for gradient systems requires greater caution than for isocratic systems.

Column parameters and flow rate

- *Stationary phase*: no change of the physico-chemical characteristics of the stationary phase permitted, i.e. chromatographic support, surface modification and extent of chemical modification must be the same; a change from Totally Porous Particle (TPP) columns to Superficially Porous Particle (SPP) columns is allowed provided these requirements are met.

- *Column dimensions*: the particle size and/or length of the column may be modified provided that the ratio of the column length (*L*) to the particle size (*dp*) remains constant or in the range between − 25 per cent to +50 per cent of the prescribed *L*/*dp* ratio. For the application of particle-size adjustment to superficially porous particles, other combinations of *L* and *dp* can be used provided that the number of theoretical plates (*N*) is within – 25 per cent to + 50 per cent, relative to the prescribed column. These changes are acceptable provided system suitability requirements are fulfilled, and selectivity and elution order of the specified impurities to be controlled are demonstrated to be equivalent. Further adjustments in method conditions (mobile phase, temperature, pH, etc.) may be required, within the permitted ranges described under System Suitability and Adjustment of Chromatographic Conditions in this chapter.

Caution is necessary when the adjustment results in a higher number of theoretical plates generating smaller peak volumes, a situation which may require adjustments to minimize extra-column band broadening by factors such as instrument connections, detector cell volume and sampling rate, and injection volume.

When the particle size is changed, the flow rate may require adjustment, because smaller-particle columns will require higher linear velocities for the same performance (as measured by reduced plate height). The flow rate is adjusted for both the change in column diameter and particle size using the following equation:

$$F_2 = F_1 \times [(dc_2^2 \times dp_1)/(dc_1^2 \times dp_2)]$$

F_1 = flow rate indicated in the monograph, in millilitres per minute;
F_2 = adjusted flow rate, in millilitres per minute;
dc_1 = internal diameter of the column indicated in the monograph, in millimetres;
dc_2 = internal diameter of the column used, in millimetres;
dp_1 = particle size indicated in the monograph, in micrometres;
dp_2. = particle size of the column used, in micrometres.

When a change is made from ≥ 3-µm to < 3-µm particles in gradient separations, an additional increase in linear velocity (by adjusting the flow rate) may be justified, provided that the column efficiency does not drop by more than 20 per cent. Similarly, a change from < 3-µm to ≥ 3-µm particles may require additional reduction of linear velocity (flow rate) to avoid reduction in column efficiency by more than 20 per cent.

A change in column dimensions, and thus in column volume, impacts the gradient volume which controls selectivity. Gradients are adjusted to the column volume by changing the

gradient volume in proportion to the column volume. This applies to every gradient segment volume. Since the gradient volume is the gradient time, t_G, multiplied by the flow rate, F, the gradient time for each gradient segment needs to be adjusted to maintain a constant ratio of the gradient volume to the column volume (expressed as L x dc^2). Thus, the new gradient time, t_{G2} can be calculated from the original gradient time, t_{G1}, the flow rate(s), and the column dimensions as follows:

$$t_{G2} = t_{G1} \times (F_1 / F_2) [(L_2 \times dc_2^2) / (L_1 \times dc_1^2)]$$

Thus, the change in conditions for gradient elution requires three steps:
(1) adjust the column length and particle size according to L/dp,
(2) adjust the flow rate for changes in particle size and column diameter, and
(3) adjust the gradient time of each segment for changes in column length, diameter and flow rate. The example below illustrates this process.

Variable	Original Conditions	Adjusted Conditions	Comment
Column length (L) in mm	150	100	User's choice
Column diameter (dc) in mm	4.6	2.1	User's choice
Particle size (dp) in µm	5	3	User's choice
L/dp	30.0	33.3	(1)
Flow rate in mL/min	2.0	0.7	(2)
Gradient adjustment factor		0.4	(3)
Gradient conditions			
B (per cent)	Time (min)	Time (min)	
30	0	0	
30	3	(3x0.4)=1.2	
70	13	[1.2+(10x0.4)]=5.2	
30	16	[5.2+(3x0.4)]=6.4	

(1) 11 per cent increase within allowed L/dp change of – 25 per cent to + 50 per cent
(2) calculated using $F_2 = F_1 [(dc_2^2 \text{ x } dp_1) / (dc_1^2 \text{ x } dp_2)]$
(3) calculated using $t_{G2} = t_{G1}$ x $(F_1 / F_2) [(L_2 \text{ x } dc_2^2) / (L_1 \text{ x } dc_1^2)]$

- *Temperature*: ± 5 °C, where the operating temperature is specified, unless otherwise prescribed.

Mobile phase

- *Composition/gradient*: adjustments of the composition of the mobile phase and the gradient are acceptable provided that:
  - the system suitability requirements are fulfilled;
  - the principal peak(s) elute(s) within ± 15 per cent of the indicated retention time(s); this requirement does not apply when the column dimensions are changed;
  - the final composition of the mobile phase is not weaker in elution power than the prescribed composition.

- *pH of the aqueous component of the mobile phase*: ± 0.2 pH units, unless otherwise prescribed.
- *Concentration of salts in the buffer component of a mobile phase*: ± 10 per cent.

Where compliance with the system suitability requirements cannot be achieved, it is often preferable to consider the dwell volume or to change the column.

Dwell volume. The configuration of the equipment employed may significantly alter the resolution, retention time and relative retentions described. Should this occur, it may be due to excessive dwell volume. Monographs preferably include an isocratic step before the start of the gradient programme so that an adaptation can be made to the gradient time points to take account of differences in dwell volume between the system used for method development and that actually used. It is the user's responsibility to adapt the length of the isocratic step to the analytical equipment used. If the dwell volume used during the elaboration of the monograph is given in the monograph, the time points (t min) stated in the gradient table may be replaced by adapted time points (t_c min), calculated using the following equation:

$$t_c = t - \frac{(D - D_0)}{F}$$

D = dwell volume, in millilitres;
D_0 = dwell volume used for development of the method, in millilitres;
F = flow rate, in millilitres per minute.

The isocratic step introduced for this purpose may be omitted if validation data for application of the method without this step is available.

Detector wavelength: no adjustment permitted.

Injection volume: except for changes from TPP columns to SPP columns, when the column dimensions are changed, injection volume adjustment may be guided by:

$$V_{inj2} = V_{inj1} (L_2 \, d_{c2}^2) / (L_1 \, d_{c1}^2)$$

V_{inj1} = injection volume indicated in the monograph, in microlitres;
V_{inj2} = adjusted injection volume, in microliters;
L_1 = column length indicated in the monograph, in centimetres;
L_2 = new column length, in centimetres;
d_{c1} = column internal diameter indicated in the monograph, in millimetres;
d_{c2} = new column internal diameter, in millimetres.

Even in the absence of any column dimension change, the injection volume may be varied provided System Suitability criteria remain within their established acceptability limits. When the injection volume is decreased, special attention is given to (limit of) detection and repeatability of the peak response(s) to be determined. An increase is permitted provided, in particular, linearity and resolution of the peak(s) to be determined remain satisfactory

Gas chromatography

Column parameters

- *Stationary phase*:
  - *particle size*: maximum reduction of 50 per cent; no increase permitted (packed columns);
  - *film thickness*: − 50 per cent to + 100 per cent (capillary columns).
- *Column dimensions*:
  - *length*: − 70 per cent to + 100 per cent.

- *internal diameter*: ± 50 per cent.
- *Temperature*: ± 10 per cent.

Flow rate: ± 50 per cent.

Injection volume and split volume: may be varied provided System Suitability criteria remain within their established acceptability limits. When the injection volume is decreased, special attention is given to (limit of) detection and repeatability of the peak response(s) to be determined. An increase is permitted provided, in particular, linearity and resolution of the peak(s) to be determined remain satisfactory.

Injection port temperature and transfer-line temperature in static head-space conditions: ± 10 °C, provided no decomposition or condensation occurs.

Supercritical fluid chromatography

Column parameters

- *Stationary phase*:
  - *particle size*: maximum reduction of 50 per cent; no increase permitted (packed columns).
- *Column dimensions*:
  - *length*: ± 70 per cent;
  - *internal* diameter: ± 25 per cent (packed columns); ± 50 per cent (capillary columns).
- *Temperature*: ± 5 °C, where the operating temperature is specified.

Composition of the mobile phase: for packed columns, the amount of the minor solvent component may be adjusted by ± 30 per cent relative or ± 2 per cent absolute, whichever is the larger; no adjustment is permitted for a capillary column system.

Flow rate: ± 50 per cent.

Detector wavelength: no adjustment permitted.

Injection volume: may be varied provided System Suitability criteria remain within their established acceptability limits. When the injection volume is decreased, special attention is given to (limit of) detection and repeatability of the peak response(s) to be determined. An increase is permitted provided, in particular, linearity and resolution of the peak(s) to be determined remain satisfactory.

QUANTIFICATION

The following quantification approaches may be used in general texts or monographs:

— *External standard method.*

- using a calibration function

Standard solutions with several graded amounts of a reference standard of the compound to be analysed are prepared in a range that has been demonstrated to give a linear response, and a fixed volume of these standard solutions is injected. With the chromatograms obtained, a calibration function is prepared by plotting the peak areas or peak heights on the ordinate against the amount of reference standard on the abscissa. The calibration function is generally obtained by linear regression. Then, a sample solution is prepared according to the method specified in the individual monograph. The chromatography is performed under the same

operating conditions as for the preparation of the calibration function, the peak area or peak height of the compound to be analysed is measured, and the amount of the compound is read out or calculated from the calibration function.

- using one-point calibration

In an individual monograph, generally one of the standard solutions with a concentration within the linear range of the calibration function and a sample solution with a concentration close to that of the standard solution are prepared, and the chromatography is performed under fixed conditions to obtain the amount of the component by comparing the responses obtained. In this method, all procedures, such as the injection procedure, must be carried out under constant conditions.

— *Internal standard method*.

- using a calibration function

In the internal standard method, a stable compound is chosen as an internal standard which shows a retention time close to that of the compound to be analysed, and whose peak is well separated from all other peaks in the chromatogram. Several standard solutions containing a fixed amount of the internal standard and several graded amounts of a reference standard of the compound to be analysed are prepared. Based on the chromatograms obtained by injection of a fixed volume of individual standard solutions, the ratio of peak area or peak height of the reference standard to that of the internal standard is calculated. A calibration function by plotting these ratios on the ordinate against the amount of the reference standard or the ratio of the amount of reference standard to that of the internal standard on the abscissa is prepared. The calibration function is generally obtained by linear regression. Then, a sample solution containing the internal standard in the same amount as in the standard solutions used for the preparation of the calibration function is prepared according to the method specified in the individual monograph. The chromatography is performed under the same operating conditions as for the preparation of the calibration function. The ratio of the peak area or peak height of the compound to be analysed to that of the internal standard is calculated, and the amount of the compound is read out or calculated from the calibration function.

- using one point calibration

In an individual monograph, generally one of the standard solutions with a concentration within the linear range of the calibration function and a sample solution with a concentration close to that of the standard solution, both containing a fixed amount of the internal standard, are prepared, and the chromatography is performed under fixed conditions to determine the amount of the compound to be analysed by comparing the ratios obtained.

— *Normalisation procedure*. Provided linearity and non-saturation of the peaks have been demonstrated, individual monographs may prescribe that the percentage content of a component of the substance to be examined is calculated by determining the area of the corresponding peak as a percentage of the total area of all the peaks, excluding those due to solvents or reagents or arising from the mobile phase or the sample matrix, and those at or below the disregard limit or reporting threshold.

Measurement of peaks

Typically, peak areas or peak heights are measured electronically.

Integration of the peak area of any impurity that is not completely separated from the principal peak is typically performed by valley-to-valley extrapolation (tangential skim) (Figure 10).

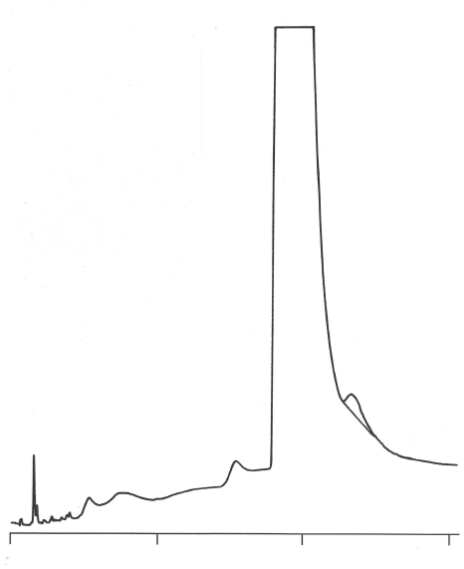


Figure 10

Detector response

The detector sensitivity is the signal output per unit concentration or unit mass of a substance in the mobile phase entering the detector. The relative detector response factor, commonly referred to as *response factor*, expresses the sensitivity of a detector for a given substance relative to a standard substance. The *correction factor* is the reciprocal of the response factor. In tests for related substances any correction factors indicated in the monograph are applied (i.e. when the response factor is outside the range 0.8-1.2).

Interfering peaks

Peaks due to solvents and reagents or arising from the mobile phase or the sample matrix are disregarded.

Reporting threshold

For related substances test, it is important to choose an appropriate threshold setting and appropriate conditions for the integration of the peak areas. In such tests the *reporting threshold*, i.e. the limit above which a peak is reported, is defined.