HOW TO CHOOSE THE RIGHT PLATE FOR THIN-LAYER CHROMATOGRAPHY?[1]

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SUMMARY

Thin-layer chromatography (TLC) is the simplest and most widely used chromatographic method for qualitative and quantitative analysis. But choice of the correct plate for TLC is the first and also the most critical step for the efficacy of the separation and accuracy of the analysis. This review article discusses selection appropriate plate for TLC.

INTRODUCTION

Thin-layer chromatography (TLC) is a chromatographic separation process in which the stationary phase consists of a thin layer applied to a solid support /1,2/. Thin-layer chromatography (TLC) is without doubt the most widely used chromatographic methods in the chromatographic techniques for qualitative and quantitative analysis of organic or inorganic compounds /3,4,5/.

In this method a chromatography tank or a suitable jar containing suitable solvent or solvent mixture and a plate coated with suitable porous sorbent layer are required to perform chromatography /3,6/. A small aliquot of sample is applied to 1-1,5 cm away from one edge of the plate to form the

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starting point /3,6/. After the spot of mixture is dry, the plate is dipped in a shallow layer of mobile phase, usually a mixture of solvents, in a closed chamber /3,5,6/ and mobile phase through the stationary phase by capillar action /5,6/. When the solvent front reaches close to the top of the plate, the plate is removed from the chamber, the mobile phase is rapidly dried under fume hood, and the spots are detected directly under ultraviolet (UV) light or make visible by application of a suitable visualization reagent /3,4/.

The separation in the TLC occurs as a result of varying degrees of affinity of the mixture components for the stationary and mobile phases in a fixed separation time /3,4/. The main steps for TLC and also for other chromatographic techniques effecting chromatograms are sample preparation, sample application, chromatographic development, and evaluation of the chromatogram /4/. But more important then, selection of the correct plate (sorbent layer and backing material etc.) based on the properties of analyte between a wide variety of adsorbent materials is the principle and most critical step for efficiency of the thin-layer chromatography and accuracy of the chromatograms.

A: COMPARISON OF THE METHODS: TLC/HPTLC/UTLC OR PLC?

The most critical phase in the TLC is the selection of the method which depends on properties of analyte, sample volume, efficiency of the separation or accuracy of the method etc., one of the four major methods is selected.

I) Classical TLC

Classical thin-layer has a thickness of 250 μm with 10-12 μm particle size /7,8,9/ and permits the analysis of 10 or less samples in 0.1 to 1000 μl amount at max. 15 cm development distance simultaneously /8,9/. The particle size distribution and the thickness of the layer are important for quality of the separation-efficacy of the method (Table 1) /10/.

TLC is generally used for one of three purposes;

1) Qualitative Analysis:

To determine the presence or absence of a specific analyte in a mixture /9,10/.

2) Quantitative Analysis:

To determine, precisely and accurately, the amount of a specific analyte in a mixture /9,10/.

3) Preparative Analysis:

To purify and isolate a specific analyte by separating it from any mixture or contaminants /9,10/.

Table 1

Common procedures of sample application in TLC*

FACTOR	QUALITATIVE	QUANTITATIVE	PREPARATIVE
Sample Volume	2-50µL	0.1-0.5µL	50-1000µL
Sample Amount	10-200µg	50-500ng	5-500mg
Sample Appl. Precision	±10%	±1%	NA
Layer Thickness	250µm	150µm	500-2000µm
Development Distance	12cm	5cm	15cm
Development Time	15-30 min	4-8 min	25-60 min
Visualization Type	Visual	Visual and Densitometric	Visual

* Adapted from Analtech's Catalog

NA: Not applicable

II) High Performance TLC (HPTLC)

High-performance TLC layers contain more uniform 200 µm (0.2 mm) thick layers and small particle size (5-6 µm) sorbents /7,8,9/. The properties of the sorbent layer and particles allow reduced zone diffusion, better and sharp separation, lower detection limits, less solvent consumption, the ability to apply more samples (up to 72) per plate with shorter migration distances and shorter running time compared to TLC layers /3,8/.

Table 2
Specifications of Thin Layer Chromatography methods*

	TLC	HPTLC	UTLC	PLC
Mean particle size	10-12 µm	5-6 µm	Monolithic	25 µm
Distribution	5-20 µm	4-8 µm	NA	5-40 µm
Layer tickness	250 µm	200 µm	10 µm	0.5 mm-2 mm
Migration distance	10-15 cm	3-6 cm	1-3 cm	10-15 cm
Sample tracks/plate	< 10	< 36 (< 72)	< 10	< 10
Sample volume	1-5 µl	0.1-0.5 µl	5-10 nl	5-20 µl
Dedection limits				
Absorption	1-5 ng	100-500 pg	...	
Fluorescence	50-100 pg	5-10 pg	10 pg	
Developing time	20-200 min	3-20 min	1-6 min	20-200 min

* Adapted from Macherey-Nagel's, and Merck's catalog
NA: Not applicable

III) Ultra thin layer chromatography (UTLC)

This precoated layer is a monolithic-porous silica /8,11/. The layer contains unmodified nano SiO_2-layer of 10 µm having mesopores of 3-4 nm and macropores of 1-2 µm. The reduced layer thickness of monolithic silica provides a 25-fold increased sensitivity compared with classical HPTLC. Moreover, the 10 µm thick layer allows detection of very low sample volumes in the pg range with highly reduced developing time (approx. 5 min) with short migration distances /8/.

IV) Preparative layer chromatography (PLC)

Preparative silica gel plates have a layer thicker than 250 microns in 5-40 µm particle size /7, 8/. Because of thickness of the layer, PLC plates allow the separation-isolation of the larger quantitities (mg to g) of samples and loading amounth of a sample increases roughly as the square root of the adsorbent layer thickness /3,8/.

In PLC, samples are not "spotted" on the TLC plate as dots, but rather are applied as band horizontally across the whole width of the plate and a specific analyte can be isolated by scraping the adsorbent layers from the plate and eluting from layer material with a suitable solvent for further analysis like HPLC or MS /8/.

Table 3
Classification of the Most Used TLC Sorbents

General class	Sorbents
Polar inorganics (hydrophilic)	Silica gel or silicic acid, alumina, diatomaceous earth (Kieselguhr), magnesium silicate (Florisil)
Polar organics	Cellulose, starch, chitine, polyamide 6 or 11
Polar bonded phases	Aminopropyl-, cyanopropyl-, and diol-modified silica
Hydrophobic bonded phases	C2-, C8-, C18-, and phenyl-modified silica; cellulose triacetate and triphenylcarbamate
Ion exchangers	
Inorganic	Zirconium phosphate, tungstate and molybdate, ammonium molybdophosphate and tungstophosphate, hydrous oxides
Organic	Polystyrene-based anion and cation exchangers, polymethacrylic acid; cellulose-based anion and cation exchangers; substance-specific complexing ligands
Impregnated layers	Silica impregnated with saturated and unsaturated hydrocarbons (squalene, paraffin oil), silicone and plant oils, complexing agents (silver ions, boric acid and borates, unsaturated and aromatic compounds), ligands (EDTA, digitonin), and transition metal salts; silanized silica gel impregnated with anionic and cationic surfactants
Gel fiitration media	Cross-linked, polymeric dextran gels (Sephadex)
Chiral phases	Cellulose, cellulose triacetate, silanized silica gel impregnated with the copper(II) complex of (2*S*, 4*R*, 2_*RS*)-*N*-(2_-hydroxydodecyl)-4-hydroxyproline (CHIRALPLATE, HPTLC CHIR)

*Adapted from reference 11

B. COMPARISON OF SORBENTS (LAYERS)

Silica gel, aluminium oxide, polyamide or cellulose?

For different types of thin layer chromatographic separation a large variety of commercial precoated layers are available.

I) Silica gel

Silica gel, the most widely used layer material, is synthesised by spontaneous polymerisation-dehydration of aqueous silicic acid /4,12/. Because of some characteristics such as porosity, flow resistance, particle size, fast developing time, the silica gel has become populer for TLC and HPTLC plates /3/. Typical properties of TLC silica gel are a silanol group level of approximately 8 /umol/m^2; pore diameter of 40, 60, 80, or 100 Å; specific pore volumes of 0.5-2.0 mL /8, 11/; and specific surface area range from 200 to 800 m^2/gr /11/.

The classical silica for TLC plates have a layer thickness of 250 μm for glass plates or 200 μm for aluminium plates, and a mean particle size of 10 - 12 μm. In the silica gel using thin layer chromatography, because of -OH groups attached to silicon atoms /6,12/, separation occurs primarily between hydrogen bonding or dipole interaction with surface silanol groups and lipophilic mobile phases and analytes are separated into groups according to their polarity /4,12/. Silica gel is recommended for separation of polar molecules such as aflatoxins, alkaloids, anabolic compounds, barbiturates, benzodiazepines, bile acid, carbohydrates,etheric oil components, fatty acids, flavanoids, glycosides, lipids, mycotoxins, nitroanilines, nucleotides, peptides, pesticides, steroids, sulfonamides, surfactants, sweeteners, tetracyclines, vitamins /11/

II) Aluminium oxide (or alumina)

Aluminium oxide is obtained after a non-uniform thermal removal of water from aluminum hydroxide at low temperature (200-600^{0}C) /3,6,11,12/. Aluminium oxide is a polar adsorbent like, but more complex than, silica gel /3/. The surface of the aluminium oxide contains hydroxyl groups, aluminum cations, and oxide anions with 50 to 350 m^2/g surface area with 20 to 150 Å average pore diameter and 0.1 to 0.4 ml spesific pore volumes /12/. Because

of features of these groups, alumina is available in basic (pH 9-10), neutral /7-8/, and acid (4-4.5) forms /3,6,11,12/. Therefore, basic compounds (e.g. amines, imines, and basic dyes) can be separated on basic aluminium oxide plates, acidic compounds (eg. phenols, sulphonic, carboxylic and amino acids) can be separated on acidic aluminium oxide plates, and neutral compounds (eg. aldehydes, ketones, and lactones) can be separated on neutral aluminium oxide plates /3,6/. Alumina has a high adsorption affinity for carbon-carbon double bonds, so this sorbent layer is preferable for analysis of aromatic hydrocarbons, herbicides, hydrazines, insecticides, metal ions, fat-soluble vitamins, lipids, lipophilic dyes, PAHs /11/.

III) Polyamide

Polyamides are organic resins carrying –CO-NH- groups on their surface /10,11/. The most commonly used polyamides are polyamide 6 (Nylon 6) and polyamide 11 /11/. They consist of polymeric caprolactam and undecanamide, respectively /11,12/. Because caprolactam monomers have shorter hydropobic chain than undecanamide, polyamide 6 is more hydrophilic than polyamide 11 /11/.

The separation mechanism is based on hydrogen bonds to amide groups of the polymer matrix as well as on ionic, dipol and electron donor/acceptor interactions /7/. Moreover, depending on the chemical structure of the analyte and the ionic character of the mobile phase, three separation mechanisms can operate with polyamide: adsorption, partition (normal- and reversed-phase), and ion exchange /11/. This flexibility allows separations of a wide range of compounds. However, it is recommended especially for natural compounds, phenols, carboxylic acids, aromatic nitrogen compounds, nucleotides, bile pigments, steroids, alkaloids and amino acids /7,12/.

IV) Cellulose

Cellulose is a polymer of D-glucopyranose units joined together by β-1, 4 glycosidic bonds /6,11,12/. Cellulose molecules carry hydroxyl groups which are readily available for hydrogen-bonding /6,12/ making cellulose an ideal adsorbent for the separation of hydrophilic substances such as amines, amino acids, antibiotics, artificial sweeteners, carbohydrates, catechols, flavanoids, PAHs, peptides, inorganic ions and nucleic acid derivatives /6,11,12/.

TLC sorbents are native fibrous cellulose and micro-crystalline cellulose /6,7,11,12/. High-purity fibrous cellulose is obtained by washing under very mild acidic conditions and with organic solvents /7,11,12,13/. The mean degree of polymerization ranges from 400 to 500 glucose units with (95 %) 2–20 μm fiber length, specific surface area about 2 m^2/g /6,7,12,13/, and molecular weight 2.5×10^5 to 1×10^6 or higher /13/. Micro-crystalline is formed by hydrolysis of high purity cellulose with HCl. The mean degree of polymerisation ranges from 40 – 200 glucose units /6,7,12,13/. Cellulose layers ideal for separations of amines, amino acids, antibiotics, artificial sweeteners, carbohydrates, catechols, flavanoids, PAHs, peptides /11/.

V) Kieselguhr (Diatomaceous earth)

This material is refined from fossilized diatoms (diatomaceous earth). It mainly consists of (approx. 90%) silicium dioxide (SiO_2) and a variety of other inorganics. Kieselguhr for TLC has 1-5 m^2/g surface area, 10^3-10^4 average pore diameter, and 1-3 ml/g specific pore volume. The pore size of the sorbent is quite variable but relatively large compared to other sorbent layers for TLC and the pore characteristics of kieselguhr allow this layer to be used for separation of polar substances such as sugars, amino acids; as an inert support for partition chromatography; and as a preadsorbent for plates with concentrating zone /11/.

C. COMPARISON OF SUPPORT MATERIALS:

Glass, plastic, or aluminum?

There are three support materials used in TLC plates.

I) Glass:

This is the most widely used support material in TLC. Glass is a inert material and has high temperature stability, chemical stability and form stability /8/. Moreover handling of this plate is easy /9/. But glass is heavy for shipping (glass plates are about 1.3 mm thick), fragile and hard to cut /8, 9/.

Table 4

Important commercially available precoated layers and examples of typical applications*

Sorbent material	Chromatographic principle	Typical applications
Aluminum oxide	Adsorption chromatography	Alkaloids, steroids, terpenes. aliphatic, aromatic and basic compounds
Cellulose Unmodified cellulose	Partition chromatography	Amino acids and other carboxylic acids as well as carbohydrates
Acetylated cellulose	Reversed phase	Anthraquinones, antioxidants, polycyclic aromatics, carboxylic acids, nitrophenols, sweeteners
Cellulose ion exchangers	Anion exchange	Amino acids, peptides, enzymes, nucleic acids
Mixed layers Cellulose DEAE/cellulose HR	Ion exchange	Mono- and oligonucleotides
Ionex ion exchangers	Anion and cation exchange	Amino acids, nucleic acid hydrolysates amino sugars, antibiotics, inorganic phosphates, cations: racemate separation in peptide synthesis
Kieselguhr	Reversed phase separations	Aflatoxins, herbicides, tetracyclines
Polyamide	Partition chromatography	Phenolic and poly phenolic natural substances

Table 4 (continued)

Silica		
Unmodified silica gel	Normal phase chromatography	Most frequent application of all TLC layers
Standard and nano silica gel also with concentrating zone chromatography		
High purity silica gel 60		Aflatoxins
Silica gel G. impregnated with ammonium sulfate		Surfactants, lipids (neonatal respiratory syndrome)
Silica gel 60, impregnated with caffeine for PAH determination	Charge transfer complexes	Polycyclic aromatic hydrocarbons (PAH) acc. to German drinking water specification (TVO)
Chemically modified layers: CHIRal plate	Enantiomer separation based on ligand exchange chromatography	Chiral amino acids, α-hydroxy-carboxylic acids and other compounds which can form chelate complexes with Cu(II) ions
Cyano-modified layer CN	NP and RP	Pesticides, phenols, preservatives, steroids
Amino-modified layer NH_2	Anion exchange, NP and RP	Nucleotides, pesticides, phenols, purine derivates, steroids, vitamins, sulfonic acids, carboxylic acids, xanthines

Table 4 (continued)

RP layers:		
RP-2, RP-8, RP-18		Nonpolar substances (lipids, aromatics)
Silica gel 60 silanized		Polar substances (basic and acidic pharmaceutical active ingredients)
RP-18 W/UV$_{35a}$, wettable	NP and RP	Aminophenols, barbiturates, preservatives, nucleobases, PAH, steroids, tetracyclines, phthalates
Spherical silica gel		
LiChrospher* Si 60	NP	Pesticides, phytopharmaceuticals
Mixed layers		
Aluminum oxide/acetylated cellulose	NP and RP	Polycyclic aromatic hydrocarbons (PAH)
Cellulose/silica gel	NP	Preservatives
Kieselguhr/silica gel	NP, reduced Adsorption capacity compared to silica gel	Carbohydrates, antioxidants, steroids, photographic developer substances

*Adapted from Macherey-Nagel's and Merck's catalog
NP: Normal phase chromatography
RP: Reverse phase chromatography

II) Plastic:

Plastic sheets (about 0.2 mm thick) are light for shipping, unbreakable and cheap /8,9/. Moreover plastic layers resistant towards all common solvents /9/ and can be easily cut into any required size /8,9/, and the spots can be cut and eluted /9/. Charring techniques can be applied for silica coated plastic TLC plates /9/. But the charring has to be done at lower temperatures (max. 185°C) because of having lower temperature stability than glass /8/.

III) Aluminium:

Aluminium supports (about 0.15 mm thick) are light for shipping, unbreakable, cheap and easier to cut than glass or plastic backed TLC plates /8,9/. These plates have a torsional strength that is almost as good as a glass plate /7,8,9/. The aluminium support has high adherence capacity, and allows cutting of the sheets to any size desired without disturbing the sorbent layer /9/. But they do not have enough form stability and chemical stability /8/.

TLC plates with three different support materials can be sprayed or dipped with purely aqueous visualization reagents without any significant damage to the layer /9/. But when concentrated mineral acids or concentrated ammonia are used in aluminum supported TLC plates, problems might arise because of low chemical stability of aluminium /7,8,9/.

Table 5

Comparison of support materials*

Physical Property	Glass	Plastic	Aluminium
Thickness (approx)	1.6 mm	0.2 mm	0.15 mm
Weight (packaging, storage requirements)	high	low	low
Torsional strength	ideal	low	relatively high
Temperature stability	high	max.185°C	high
Susceptible to breakage	yes	no	no
Can be cut with scissors	no	yes	yes
Chemical resistance			
Against solvents	high	high	high
Against mineral acids and conc. NH_4	high	high	low
Binder stability in water	depends	very	limited

* Adapted from Macherey-Nagel's and Analtech's catalog

E. IMPREGNANT LAYERS:

The impregnation of layers with buffers, chelating agents, metal ions, etc. improves the resolution or detection characteristics of layers for certain compounds /3/.

I) Sodium Hydroxide (0.1 N) Modified Silica Gel

0.1 N sodium hydroxide is used instead of water to prepare the slurry for these plates. The addition of NaOH makes the plates more basic and improve the separation of particularly organometallics and some acidic classes /9/.

Table 6
Types of sorbents and supports for precoated layers*

Sorbent material	Support
Aluminum oxide 60. ISO	Aluminum foil, glass plate, plastic film
Cellulose (unmodified)	Aluminum foil, glass plate, plastic film
Cellulose (acetylated)	Glass plate, plastic sheet
PEI-Cellulose	Glass plate, plastic sheet
Silica gel 40	Glass plate
Silica gel 60	Aluminum foil, glass plate, plastic film
Kieselguhr	Aluminum foil, glass plate
liChrospher* Si 60	Glass plate
Si 50000	Glass plate
Si 60 RAMAN	Aluminum foil
Silica gel. modified	
CHIR (chiral)	Glass plate
CN (cyano)	Glass plate
DIOL	Glass plate
NH_2 (amino)	Aluminum foil, glass plate
Silica gel 60 caffeine-impregnated	Glass plate

Table 6 (continued)

Sorbent material	Support
Silical G ammonium sul fate-impregnated	Glass plate
Silica gel 60 silanized (RP-2). RP-8	Glass plate
RP-IS	Aluminum foil, glass plate
Mixed layers	
Aluminum oxide/acetylated cellulose	Glass plate
Cellulose/silica	Glass plate
Cellulose **300** DEAE/cellulose **300 HR**	Glass plate
Silica gel 60/ kieselguhr	Aluminum foil, glass plale
Two-zone layers[a)]	
Si 50000 (con.)- silica gel 60 (sep.)	Aluminum foil, glass plate
Si 50000 (con.). RP-18 (sep.)	Glass plate
Kieselguhr (con), silica gel 60 (sep.)	Glass plale
Silica gel 60 (1st sep.), RP-18 (2nd sep.)	Glass plate
Special layers	
IONEX (ion exchange resin)	Plastic sheet
Polyamide 6	Plastic sheet
Polyamide 11	Aluminum foil, glass plate

*Adapted from reference 4
con. = concentrating zone
sep. = separation zone

II) Carbomer (0.33%) Modified Silica Gel

These sorbents are impregnated 0.33% carbomer and used in the analysis of mannitol/sorbitol /9/.

III) Silver Nitrate (5-20%) Impregnated Silica Gel

These sorbents are impregnated with between 5% and 20% silver nitrate /9/. The addition of silver nitrate allows increased discrimination of, particularly, carbon-carbon double bonds containing compounds such as fatty acids, fatty acid cholesterol esters, fatty acid methyl esters, terpenoids and prostaglandins /9, 11/.

IV) Magnesium Acetate (5,7.5, 10%) Impregnated Silica Gel

These sorbents are impregnated with 5, 7.5, or 10% magnesium acetate. The addition of magnesium acetate decreases the acidity of the layer and allows increased discrimination of phospholipids /9/.

V) Potassium Oxalate (1%) Impregnated Silica Gel

These plates are impregnated with 1% potassium oxalate and acquire a separation characteristic which aids in the discrimination of polyphosphoinositides /9/.

VI) Ammonium Sulfate (5%) Impregnated Silica Gel

These plates contain 5% ammonium sulfate, eliminating the need to use sulfuric acid for charring. Just evaporate the developing solvent until the plate is completely dry, then heat at 150-200°C for 30 to 60 minutes to achieve charring /9/.

VII) Alumina G

These plates contain calcium sulfate hemihydrate as a binder with aluminum oxide as the adsorbent. The pH is neutral to slightly basic /9/.

VIII) Diethylaminoethyl (DEAE) Avicel Cellulose

The cellulose molecule carries positive charges at neutral and acidic pH and hydrophilic nature of the cellulose makes it well suited to ion exchange separations. DEAE cellulose is widely used for separation of negatively charged molecules by ion exchange chromatography /9/.

TLC plates are available with mixed layers containing both DEAE Cellulose and unmodified cellulose /9/. Mixed-layer plates have lower ion exchange capacity and may provide higher chromatographic mobility for negatively charged molecules such as DNA adducts, DNA and RNA fragments, food dyes and steroids /9, 11/.

F. REVERSE-PHASE PLATES

The basis of chromatographic separation in "Reversed Phase Chromatography" is just the opposite of that occuring in normal phase chromatography. In normal phase thin chromatography the sorbent layer (stationary phase) is a polar material and adsorption occurs as a result of polar interactions /3, 9/. Thus, in normal phase chromatography, while more polar solutes are bound most strongly near the origin, non-polar solutes move with mobile phase and polar samples will exhibit lower Rf values than non-polar samples. In this type of chromatography Rf values of analytes can be increased by making the mobile phase more polar /3, 9/.

In Reversed Phase Chromatography, however, impregnation of the silica gel layer with mineral oil or C_2-C_{18} hydrocarbons makes the layer less polar than the mobile phase and adsorption occurs as a result of nonpolar interactions. Thus, in Reversed Phase Chromatography, while non-polar solutes are most strongly retained on sorbent layer polar solutes move with mobile phase-will exhibit lower Rf values than polar samples and Rf values can generally be increased by making the mobile phase less polar /9/.

G. LAYERS FOR ENANTIOMER SEPARATIONS

The phenomenon of chirality is a form of stereoisomerism and relevent to the relationship between two or more isomers having the same structure but with different configurations /13/.

Commercial plates (Chiralplate /7/ and HPTLC CHIR /8/) consist of a glass plate coated with a reversed-phase silanized silica gel impregnated with the Cu(II) ions and (2S,4R,2RS)-N-(2'-hydroxydodecyl)-4-hydroxyproline /7,13/. And separation of the enantiomers is based on ligand exchange, i.e. formation of ternary mixed-ligand complexes with the Cu(II) ions; differences in the stability of the diastereomeric complexes cause chromatographic separation /7,13/.

Table 7: Application in Normal- and Reversed-Phase TLC*

Sorbent	Substance class
Silica gel	Aflatoxins, alkaloids, anabolic compounds, barbiturates, benzodiazepines, bile acid, carbohydrates, etheric oil components, fatty acids, flavanoids, glycosides, lipids, mycotoxins, nitroanilines, nucleotides peptides, pesticides, steroids, sulfonamides, surfactants, sweeteners, tetracyclines, vitamins
Alumina	Aromatic hydrocarbons, herbicides, hydrazines, insecticides, metal ions, fat-soluble vitamins, lipids, lipophilic dyes, PAHs
Cellulose	Amines, amino acids, antibiotics, artificial sweeteners, carbohydrates, catechols, flavanoids, PAHs, peptides
Alkyl- and aryl-bonded phases	Alkaloids, amides, amines, amino acids, amino phenols, antibiotics, antioxidants, barbiturates, drugs, fatty acids, indole derivatives, nucleobases, oligopeptides, optical brighteners, PAHs, peptides, pharmaceuticals, phenols, phthalates, porphyrins, preservatives, steroids, surfactants, tetracyclines
Amino-modified silica gel	Nucleosides, nucleotides, pesticides, phenols, purine derivatives, steroids, vitamins
Cyano-modified silica gel	Analgesics, antibiotics, benzodiazepines, carboxylic acids, carotenoids, pesticides, phenols, steroids
Diol-modified silica gel	Nucleosides, pesticides, pharmaceuticals, phospholipids

Table 7 (continued)

Sorbent	Substance class
Cellulose-based ion exchangers	DNA adducts, DNA and RNA fragments, dyes for food, inorganic ions, steroids
Polystyrene-based ion exchangers	Amines, amino acid, inorganic ions, peptides, purine and pyrimidine derivatives
Ammonium tungstophosphate	Amines, amino acids, indole derivatives, oligopeptides, polyamines, sulfonamides
Silica gel impregnated with paraffin, pestisilicon, and plant oils	Barbiturates, carboxylic esters, fatty acid derivatives, nitrophenols, PCBs, peptides, pesticides, phenols, steroids, surfactants, triazines
Silanized silica gel impregnated with anionic and cationic surfactants	Aliphatic and aromatic amines, alkaloids, amino acids, amino sugars, carboxylic and sulfanilic acids, drugs, indole derivatives, nucleobases, nucleosides, nucleotides, peptides, dipeptides, polypeptides, phenols, phenothiazine bases, steroids, sulfonamides, watersoluble food dyes
Silver-impregnated silica gel	*cis*-Monoenoic esters, *cis/trans*- and *trans/trans*-Dienoic esters, fatty acid cholesteryl esters, positional and geometric isomers of fatty acid methyl esters, terpenoids, prostaglandins

*Adapted from reference 11

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