
Phthalates

(Butylbenzyl-, Diallyl-, Dibenzyl-, Di-*n*-butyl-, Dicyclohexyl-, Diethyl-, Di-(2-ethylhexyl) phthalate)

Method number	2
Application	Air analysis
Analytical principle	High performance liquid chromatography
Completed in	March 2006

Summary

The method permits the determination of phthalates, e.g. butylbenzyl-, diallyl-, dibenzyl-, di-*n*-butyl-, dicyclohexyl-, diethyl and di-(2-ethylhexyl)phthalate (DEHP) in a concentration range from 0.3 to 20 mg/m³. The currently valid MAK value and occupational exposure limit (OEL) of DEHP is 10 mg/m³ [1, 2].

Sampling is carried out by drawing ambient air through a membrane filter and a sampling tube filled with silica gel using a suitable pump. For extraction of the phthalates, the loaded membrane filter and the content of the silica gel tube are covered with methanol and shaken. Analysis is performed by high-performance liquid chromatography equipped with UV detection. Quantitative evaluation is carried out using a calibration graph.

Characteristics of the method

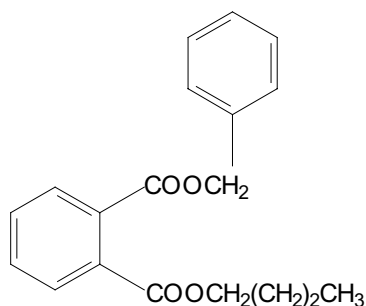
Precision:

Standard deviation (rel):	$s = 0.85-1.51\%$
Mean variation:	$u = 2.76-4.91\%$ in the concentration range of $c = 0.294-0.977 \text{ mg/m}^3$ of each phthalate and for $n = 10$ determinations
Standard deviation (rel):	$s = 0.66-1.67\%$
Mean variation:	$u = 2.15-5.43\%$ in the concentration range of $c = 2.90-9.56 \text{ mg/m}^3$ of each phthalate and for $n = 10$ determinations
Standard deviation (rel):	$s = 0.79-1.86\%$
Mean variation:	$u = 2.57-6.05\%$ in the concentration range of $c = 5.77-19 \text{ mg/m}^3$ of each phthalate and for $n = 10$ determinations
Limit of quantification:	$0.011-0.025 \text{ mg/m}^3$ for a 60-litre air sample
Recovery:	$\eta > 0.966-0.978$ (96.6–97.8%)
Sampling recommendation:	Sampling time: 1–2 h Sample volume flow: 60 L/h

Phthalates (Phthalic acid esters)

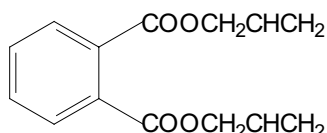
Esters of phthalic acid are usually water insoluble, odorless and low volatile liquids. They are mainly used as plasticizers. They also serve as preliminary products for, e.g., thermosets and lacquer resins, or greaseless lubricants. Information on the toxicity of phthalates (e.g. DEHP) is given in the MAK value documentation [3]. Phthalates occur nearly ubiquitous. Main reasons for that are their high production quantities and respectively their manifold fields of application.

Butylbenzyl phthalate (benzylbutyl phthalate, phthalic acid benzyl-*n*-butylester BBP) [CAS-Nr. 85-68-7]



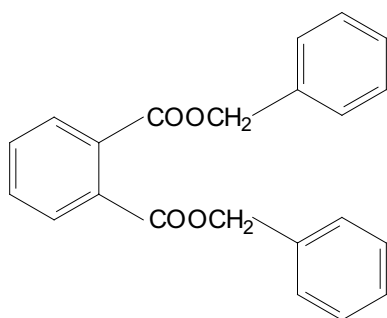
Benzyl-*n*-butylphthalate is a colourless, odorless and water-insoluble liquid (molecular weight 312.4 g/mol, freezing point ca. -40°C , boiling point ca. $250\text{--}270^{\circ}\text{C}$ at 26 hPa). It is soluble in most organic solvents. BBP is mainly used as an additive for weather-proof nitrocellulose lacquers and polyvinyl chloride products.

Diallyl phthalate (phthalic acid diallyl ester, DAP) [CAS-Nr. 131-17-9]



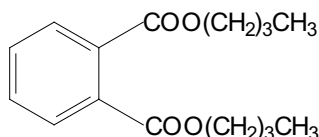
Diallylphthalate is a colourless, odorless and water-insoluble liquid (molecular weight 246.3 g/mol, freezing point ca. -70°C and boiling point ca. $190\text{--}195^{\circ}\text{C}$ at 23 hPa). It is soluble in most organic solvents. Due to its polymerizing characteristic, it is used as a component in polymerization-mixtures during the manufacture of contact- and casting resins.

Dibenzyl phthalate (phthalic acid dibenzyl ester) [CAS-Nr. 523-31-9]



Dibenzyl phthalate is a slightly yellowish powder (molecular weight 346.4 g/mol, freezing point ca. 41°C). It is soluble in most organic solvents. Due to its low light-resistance dibenzyl phthalate so far is of no greater commercial relevance.

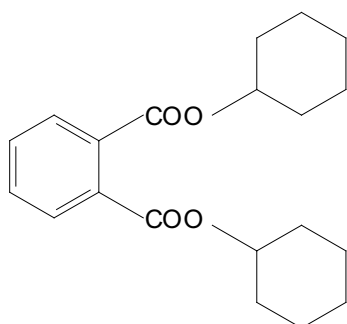
Di-*n*-butyl phthalate (phthalic acid di-*n*-butyl ester, DnBP) [CAS-Nr. 84-74-2]



Di-*n*-butyl phthalate is a colourless, odorless and water-insoluble liquid (molecular weight 278.3 g/mol, freezing point ca. -37°C and boiling point ca. $212\text{--}216^{\circ}\text{C}$ at 26 hPa). It is soluble in most organic solvents. Due to its high weather and light resis-

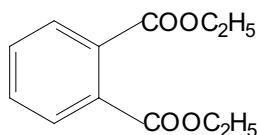
tance, it has become one of the most important gelatinizing plasticizer for lacquers and adhesives. For polyvinyl acetate-dispersions it is used as external plasticizer. Di-*n*-butyl phthalate is often used in combination with other high molecular weight phthalates for plasticising polymers. DnBP is used as a solvent for oil-soluble dyes, insecticides, and other organic compounds. DBP has also been added to personal care products for various reasons. Diisobutyl phthalate (DiBP, CAS-Nr. 84-69-5) possesses similar characteristics, but is slightly more volatile than di-*n*-butyl phthalate, and its gelatinizing capacity for nitro-cellulose is also lower.

Dicyclohexyl phthalate (phthalic acid dicyclohexyl ester)
[CAS-Nr. 84-61-7]

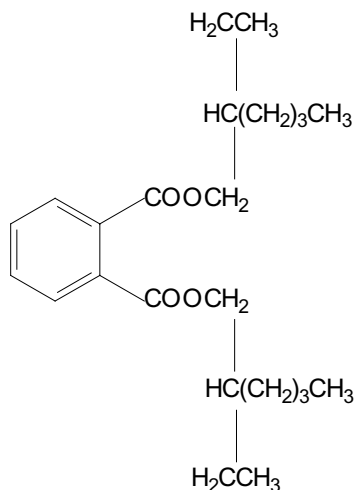


Dicyclohexyl phthalate is a slightly yellowish powder (molecular weight 330.4 g/mol, freezing point ca. 63 °C, and boiling point ca. 210–235 °C at 26 hPa). It is soluble in most organic solvents. Dicyclohexyl phthalate is mainly used for hot-sealable nitrocellulose lacquers that are highly resistant to water. It is further applied as an additive for thermoplastics for the production of poly-adhesive papers.

Diethyl phthalate (phthalic acid diethyl ester, DEP)
[CAS-Nr. 84-66-2]



Diethyl phthalate is a colourless and water-insoluble liquid (molecular weight 222.2 g/mol, freezing point ca. -3 °C and boiling point ca. 175–179 °C at 26 hPa). It is soluble in most organic solvents. To some extent diethyl phthalate is used for synthetic materials made with cellulose acetate. Moreover, it is used for denaturation of ethanol and also as perfume fixative.

Di-(2-ethylhexyl) phthalate (bis-(2-ethylhexyl) phthalate, phthalic acid-bis-(2-ethylhexyl) ester, DEHP) [CAS-Nr. 117-81-7]

Di-(2-ethylhexyl) phthalate is a colourless and water-insoluble liquid with a very low volatility (molecular weight 390.5 g/mol, freezing point ca. -50°C and boiling point ca. $260-265^\circ\text{C}$ at 26 hPa). It is soluble in most organic solvents.

PVC is gelatinized particularly well by DEHP; DEHP plasticised PVC polymers exhibit outstanding mechanic properties. They are weatherproof and used in electrical installations, for foils and artificial leather manufacturing. DEHP is also used for the production of nitrocellulose-lacquers due to its outstanding resistance to light.

Up to the year 2000, the share of DEHP in the total production of plasticisers was between 60 and 70 %, but decreased continuously to 21 % in the year 2005. To date diisooctyl (DiNP) or diisodecyl phthalate (DiDP) are used as substitutes, comprising in the meanwhile a share of 60 % in the total plasticizer production in Europe of approximately 1 mio. tons/a.

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Phthalates

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1 General principles

The method permits the determination of the phthalates benzyl butyl-, diallyl- dibenzyl-, di-*n*-butyl-, dicyclohexyl-, diethyl and di-(2-ethylhexyl)phthalate (DEHP) in a concentration range from 0.3 to 20 mg/m³. The currently valid MAK value for DEHP is 10 mg/m³ [1, 2].

For sample collection, ambient air is drawn with a suitable pump through a membrane filter and a sampling tube filled with silica gel. For extraction, the membrane filter loaded with phthalates and the content of the silica gel tube are covered with methanol and shaken. The quantitative determination is carried out using liquid chromatography equipped with UV detection.

2 Equipment, chemicals and solutions

2.1 Equipment

- Pump for personal sampling, suitable for flow rates of 60 L/h
- Gas meter
- High performance liquid chromatograph with diode array detector (DAD)
- Data evaluation software
- Ultrapure water system
- Analytical balance
- Three-part filter holders (diameter 37 mm), e.g. Millipore No. 670045037
- Silica gel tubes (6 × 70 mm), e.g. Supelco ORBO 502
- Cellulose acetate filters (diameter 37 mm, pore size 0.8 µm) e.g. Macherey & Nagel No. 68000080037, Osmonics A08SP04700, or Sartorius 11104

Due to the blind value problematic (see also Section 8.5), the use of cellulose acetate filters is absolutely necessary. If other filter materials are used (e.g. cellulose mixed ester), then often higher blind values are observed that can cause massive interferences, making an evaluation of the chromatograms of benzylbutyl phthalate and dicyclohexyl phthalate hardly possible or impossible. In general, every new filter-charge should be analysed for their blind values in respect to all phthalates prior to use.

- Disposable filters, e.g. Gelman Acrodisc 13 CR PTFE
- 2- and 5 mL volumetric flasks
- Graduated cylinder
- 2.5 mL volumetric pipettes
- 10–500 µL gas tight microliter syringe
- 4 mL amber glass vials with screw-top and rubber/PTFE seal
- 1.5 mL glass autosampler vials with beaded rim and rubber/PTFE septa

The laboratory glassware listed above should be cleaned in a dishwasher, dried at room temperature and afterwards rinsed with methanol.

2.2 Chemicals

- Methanol HPLC quality, e.g. from J. T. Baker, No. 8402
- Acetonitrile HPLC quality, e.g. from J. T. Baker, No. 9017
- Benzyl-*n*-butyl phthalate, > 98%, e.g. from Merck, No. 821030
- Di-*n*-butyl phthalate, > 98%, e.g. from Fluka, No. 80102
- Di-(2-ethylhexyl) phthalate, > 98%, e.g. from Merck, No. 821874
- Diallyl phthalate, > 98%, e.g. from Fluka, No. 36925
- Dibenzyl phthalate, > 97%, e.g. from Lancaster, No. 4985
- Dicyclohexyl phthalate, > 99%, e.g. from Aldrich, No. 30.615-0
- Diethyl phthalate, > 99%, e.g. from Merck, No. 822323
- Phthalate Ester Mix, e.g. from Supelco, Custom-Mix DE 586

Chemicals should be stored in the refrigerator at a maximum temperature of +4 °C. The date when a flask with a chemical is opened for the first time must be marked on the flask.

2.3 Solutions

Mobile phase	Eluent A:	Acetonitrile in ultrapure water 70 % (v/v) (Conductivity of the water > 17.6 MΩ · cm)
	Eluent B:	Acetonitrile

2.4 Calibration standards

By using the chemicals listed in Section 2.2, the following solutions are prepared:

Starting solutions:

Each 25 mg of benzylbutyl-, diallyl-, dibenzyl-, di-n-butyl-, dicyclohexyl-, diethyl phthalate, and 40 mg of di-(2-ethylhexyl) phthalate are weighed in separate 5 mL volumetric flasks, and the flasks are filled to the mark with methanol.

Stock solution:

200 μ L of each starting solution are pipetted into 5 mL volumetric flask, and the flasks are filled to the mark with methanol.

All solutions are stable at -18°C for at least 3 month.

Calibration standard solutions:

From the stock solution, the following calibration standard solutions are prepared by dilution to 5 mL using methanol. Table 1 shows the pipetting procedure to be followed.

Table 1. Pipetting scheme for the preparation of the calibration standard solutions.

Calibration standard solution No.	Volume of the stock solution [μL]	Concentration of butyl benzyl-, diallyl-, dibenzyl-, di- <i>n</i> -butyl-, dicyclohexyl-, and diethyl phthalate [$\mu\text{g/mL}$]	Concentration of di-(2-ethylhexyl) phthalate [$\mu\text{g/mL}$]
1	20	0.80	1.28
2	40	1.60	2.56
3	60	2.40	3.84
4	80	3.20	5.12
5	100	4.00	6.40
6	120	4.80	7.68
7	140	5.60	8.96
8	160	6.40	10.24
9	180	7.20	11.52
10	200	8.00	12.80

Control sample for precision:

As for the control sample used to check the precision within an analytical series, a standard of mean concentration is used, related to the calibration range of the phthalates, which is $c(\text{phthalates}) = 4.0 \mu\text{g/mL}$ and $6.4 \mu\text{g/mL}$. 100 μL of the standard solution are transferred into a 5 mL volumetric flask using a gas tight syringe, and filled to the mark with methanol.

Control sample for accuracy:

As a control sample for accuracy, a standard of mean concentration is used, related to the calibration range for $c(\text{phthalates}) = 5.0 \mu\text{g/mL}$. 25 μL of the phthalate ester mix are transferred into a 10 mL volumetric flask using a gas tight syringe, and filled to the mark with methanol.

The control samples are stable at -18°C for at least 1 month.

3 Sample collection and preparation

With a flow-stabilized pump, ambient air is drawn through the membrane filter and the silica gel tube with a flow rate of 1 L/min. After sample collection, the sampling layers are closed with provided caps and plastic caps.

For sample preparation, the membrane filter and the content of the silica gel tubes are transferred into a 4 mL sample vial and covered with 2.5 mL methanol. The sample vials are sealed and shaken afterwards for 60 min in a shaker.

For each silica gel and membrane filter charge, blank value determinations are performed (see Section 8.5).

From the supernatant of the prepared sample, an aliquot of approx. 1 mL is removed with a disposable syringe and filtered through a disposable filter into a 1.5 mL auto-sampler vial. The vial is then sealed and its content is analysed.

4 Operating conditions for HPLC

Apparatus	HPLC equipped with DAD (e. g. Agilent 1100)	
Column:	Material:	Kromasil C18
	Length:	250 mm
	Internal diameter:	4 mm
	Particle size	5 μm
Column temperature:	23 °C	
Mobile phase:	Eluent A: Acetonitrile in ultrapure water (70 Vol.-%)	
	Eluent B: Acetonitrile	
Gradient programme:	0–3 min:	100 % A
	3–13 min:	→ 100 % B
	13–23 min:	100 % B
	<i>Equilibration:</i>	
	> 23 min:	→ 100 % A
Flow rate:	0.8 mL/min	
Detection wavelength:	230 nm	
Injection volume:	25 μL	

Figure 1 shows an example of a chromatogram, obtained under the conditions given above.

5 Analytical determination

25 μL of the prepared sample solution are injected into the liquid chromatograph using an autosampler. The samples are analysed with repeated determinations under the operating conditions described in Section 4.

If the concentrations calculated are outside the calibration range, the sample solution must be suitably diluted with methanol and analysed again.

6 Calibration

The calibration graph is drawn using the calibration standard solutions described in Section 2.4. 25 µL of each calibration standard solution are injected into the HPLC and analysed under the same conditions as the sample solutions. The calibration graph is obtained by plotting the detected peak areas against the corresponding concentrations. The calibration graph is linear in the investigated concentration range.

In order to check the calibration function, control samples should be analysed at each working day. The calibration must be renewed, if the analytical conditions changed or quality control shows it to be necessary.

7 Calculation of the analytical results

The concentrations of the phthalates in the workplace air are calculated using the concentrations of the substances in the solution calculated by the data analysis unit. The data analysis unit uses the calibration graphs established during the calibration performed for this purpose.

The concentrations of the phthalates in the workplace air are calculated from the concentrations, taking dilution steps and the sampled air volume into account.

The concentrations by weight, ρ of phthalates in mg/m³, are calculated according to equation (1).

$$\rho = \frac{(c - c_{blind}) \times 0.001 \times 2.5}{\eta \times V_{air}} \quad (1)$$

For the conversion to 20 °C and 1013 hPa, equation (2) is used.

$$\rho_0 = \rho \times \frac{273 + t_a}{293} \times \frac{1013}{p_a} \quad (2)$$

Where:

- c is the concentration in the sample solution in µg/mL
- c_{blind} is the concentration of the blank value in the sample solution in µg/mL
- ρ is the concentration by weight of the phthalates in the workplace air in mg/m³
- ρ_0 is the concentration by weight of the phthalates in the workplace air in mg/m³, at 20 °C and 1013 hPa
- 0.001 is the conversion factor from µg to mg
- 2.5 is the conversion factor for the extraction volume in mL
- η is the recovery
- V_{Luft} is the air sample volume in m³
- t_a is the temperature in the air during sampling in °C
- p_a is the atmospheric pressure during sampling in hPa

8 Reliability of the method

The characteristics of the method were determined according to EN 482 [4].

8.1 Precision

To determine the precision within the minimum measurement range, sampling layers were spiked with phthalates in defined concentrations. Afterwards, air was drawn through the sampling layer for 1 hour using a flow rate of 1 L/min. Preparation and analyses of the sampling layers were carried out as described in Sections 3 and 4. Each 10 samples were investigated per specified concentration. The following data were obtained (Table 2).

Table 2. Standard deviation (rel) and mean variation u for $n = 10$ determinations.

Substance	Concentration [mg/m ³]	Workplace area [µg/mL]	Standard deviation (rel) [%]	Mean variation u [%]
Butylbenzyl phthalate	0.294	0.8–8.0	1.38	4.49
	2.90		1.56	5.07
	5.77		1.50	4.88
Diallyl phthalate (DAP)	0.496	0.8–8.0	1.24	4.03
	4.83		0.66	2.15
	9.68		0.79	2.57
Dibenzyl phthalate	0.298	0.8–8.0	1.51	4.91
	2.94		1.67	5.43
	5.81		1.00	3.25
Di- <i>n</i> -butyl phthalate	0.476	0.8–8.0	1.49	4.84
	4.70		1.39	4.52
	9.31		1.44	4.68
Dicyclohexyl phthalate	0.484	0.8–8.0	0.85	2.76
	4.80		1.18	3.84
	9.47		1.21	3.93
Diethyl phthalate (DEP)	0.302	0.8–8.0	1.08	3.51
	2.94		1.44	4.68
	5.88		1.86	6.05
Di-(2-ethylhexyl) phthalate (DEHP)	0.977	1.28–12.80	0.85	2.76
	9.56		1.18	3.83
	19.00		1.23	4.00

8.2 Recovery

The recoveries of the individual phthalates were calculated using the data obtained from the determination of precision within the minimum measurement range. The recoveries for the investigated phthalates are listed in Table 3.

Table 3. Recoveries η of the individual phthalates.

Substance	Recovery η
Benzyl- <i>n</i> -butyl phthalate	0.975
Diallyl phthalate	0.976
Dibenzyl phthalate	0.973
Di- <i>n</i> -butyl phthalate	0.966
Dicyclohexyl phthalate	0.979
Diethyl phthalate	0.965
Di-(2-ethylhexyl) phthalate	0.971

8.3 Limit of quantification

The limit of quantification was determined according to DIN 32645 [5]. After performing a 10-point-calibration within the concentration range from 0.80 to 8.00 $\mu\text{g/mL}$, and from 1.28 to 12.80 $\mu\text{g/mL}$, respectively, the limits of quantification were calculated for a sampled air volume of 60 L. The results are shown in Table 4.

Table 4. Limit of quantification for a sample air volume of 60 L.

Substance	Limit of quantification [mg/m^3]
Benzyl- <i>n</i> -butyl phthalate	0.011
Diallyl phthalate	0.013
Dibenzyl phthalate	0.012
Di- <i>n</i> -butyl phthalate	0.017
Dicyclohexyl phthalate	0.013
Diethyl phthalate	0.018
Di-(2-ethylhexyl) phthalate	0.025

8.4 Shelf-life

To check the shelf-life, the sampling layers were spiked as described in Section 8.1 and afterwards stored at first for 7 days at room temperature followed by a storage temperature of -18°C .

After storage of 1, 7, and 14 days, repeated determinations were carried out. For that, the sampling layers were prepared and analysed according to Sections 3 and 4. Within a time period of two weeks, no significant changes in the phthalate concentrations could be observed.

8.5 Blank values of the sample carrier

Silica gel tubes and membrane filters may exhibit a detectable phthalate blank value, which must also be analysed for each batch. However, a correction of the blank value by means of system software should be conducted, if the blank value exceeds the quantification limit of a phthalate. For determining the blank value of a silica gel and membrane filter batch, the content of a silica gel tube and a membrane filter are placed in a screw-top vial and prepared and analysed in the same way as the samples.

9 Discussion of the method

Through modifications of the chromatographic conditions (e.g. column, gradient), further plasticizers such as diisobutyl phthalate (DiBP), diisononyl- (DiNP), or diisodecyl phthalate (DiDP) can be determined with the analytical method presented herein. In Figure 2, a chromatogram of a calibration standard for long-chain phthalates is shown. In respect to the structurally related phthalates (e.g., DnBP and DiBP, but also DEHP, DiNP and DiDP), it has to be taken care that the peaks are chromatographically separated. Under certain conditions, a chromatographic separation is not possible, e.g. if DiNP of type 1 (CAS No. 68515–48-0) is analysed simultaneously with DiDP, because DiNP 1 process-orientated contains ca. 15–25 % of DiDP components.

10 References

- [1] DFG (Deutsche Forschungsgemeinschaft) (2008) List of MAK and BAT values 2008. Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, Report No. 44. Wiley-VCH, Weinheim.
- [2] TRGS 900 Arbeitsplatzgrenzwerte. GMBI 1/2006, zuletzt geändert und ergänzt: Juni 2008.
- [3] Greim H (Hrsg.) (2002) Di-(2-ethylhexyl) phthalat (DEHP). Gesundheitsschädliche Arbeitsstoffe, Toxikologisch-arbeitsmedizinische Begründungen von MAK-Werten, 35. Lieferung, Wiley-VCH, Weinheim
- [4] EN 482 Workplace atmospheres – General requirements for the performance of procedures for the measurement of chemical agents, European Standard, Issue: October 2006.
- [5] DIN 32645 – Chemical analysis; decision limit; detection limit and determination limit. Issue: May 1994, Beuth Verlag, Berlin

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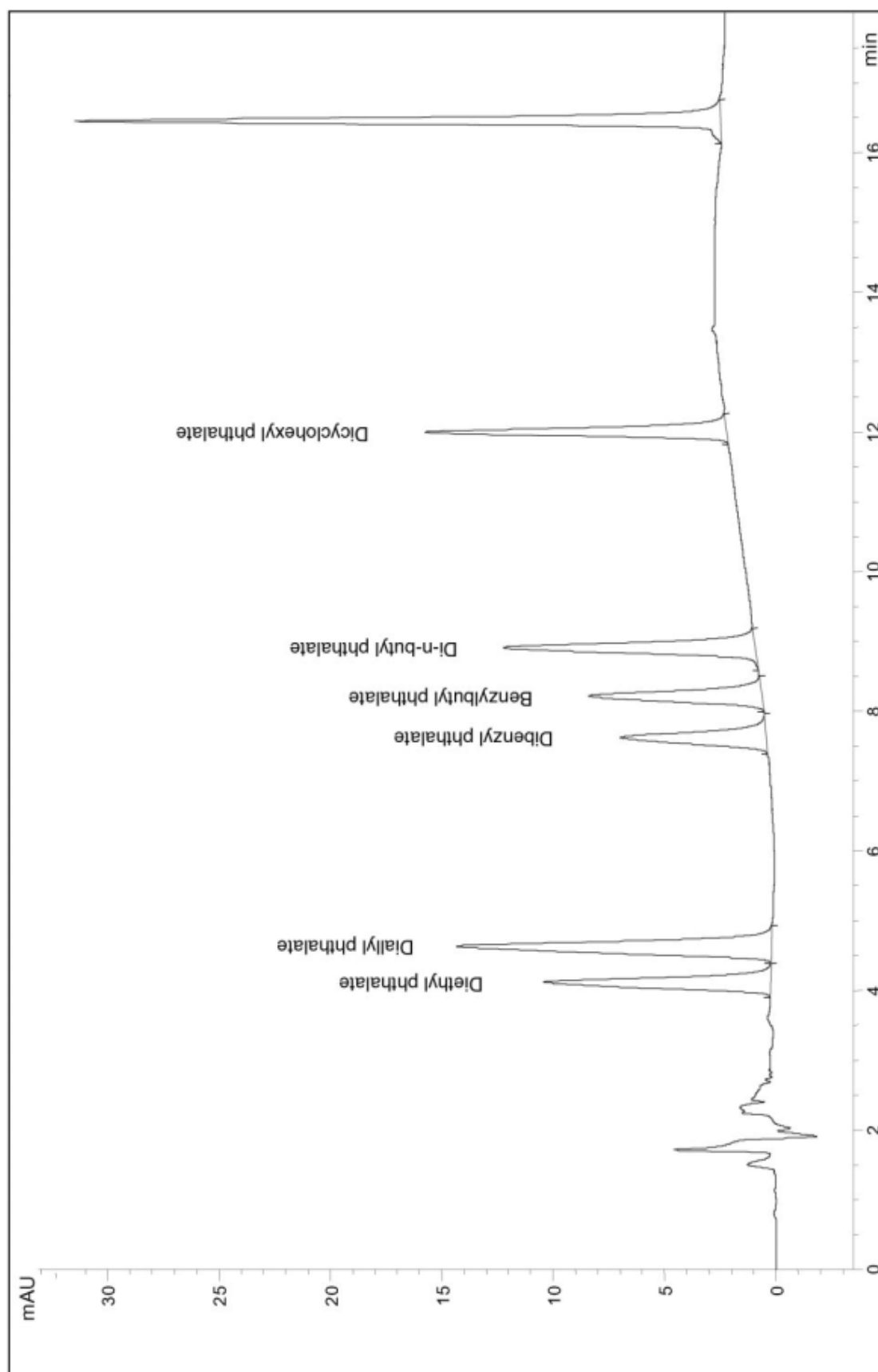


Fig. 1. Example of a HPLC chromatogram for separation of phthalates with concentrations between 4.0 and 12.0 $\mu\text{g/mL}$ (see Section 4 for the chromatographic conditions).

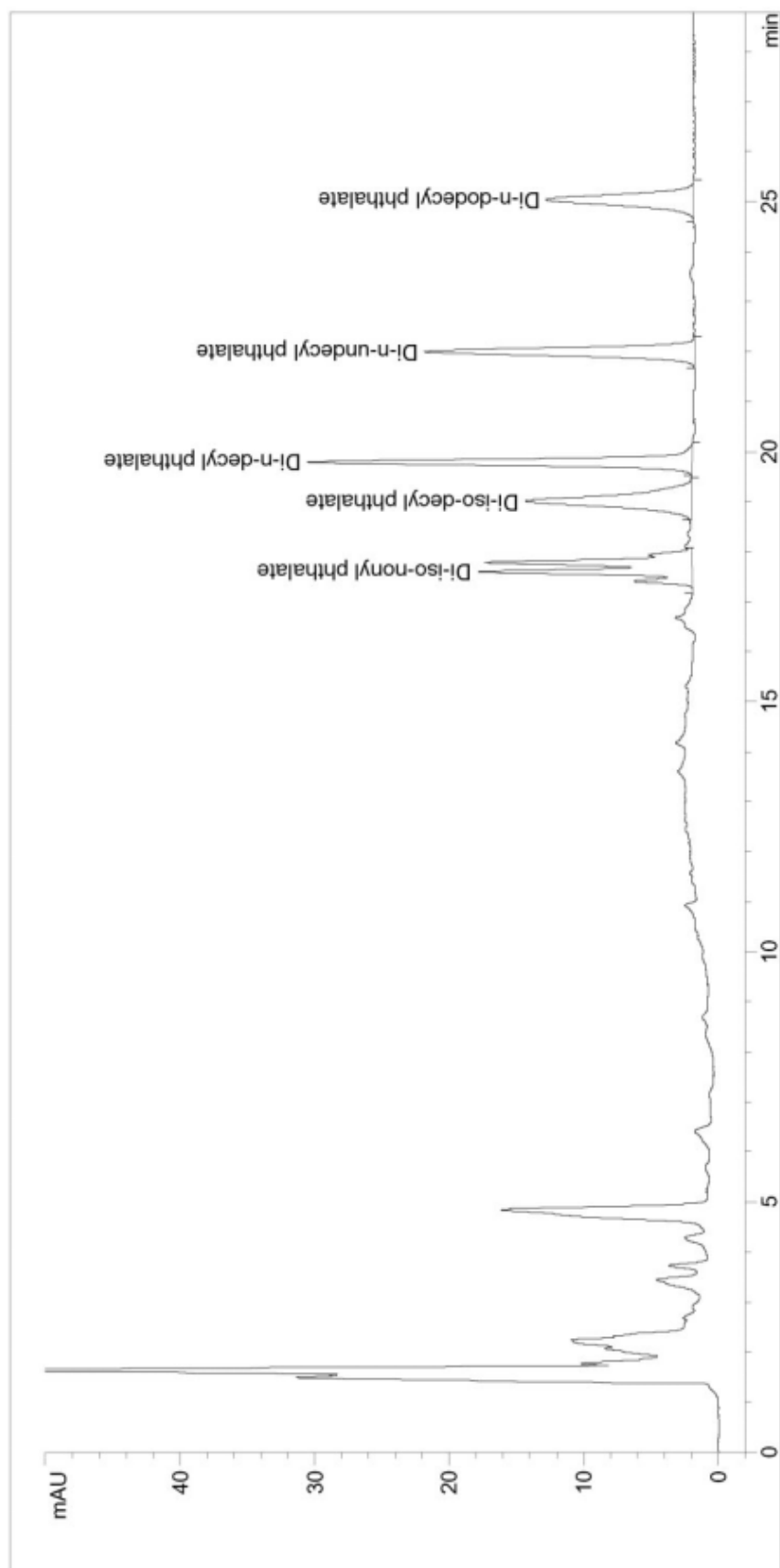


Fig. 2. Example of a HPLC chromatogram of calibration standards for long-chain phthalates.

Concentration by weight: 7.0 µg/mL

Apparatus and operating conditions: like Section 4

Column: Zorbax XDB C8, 5 µm, 250 x 4.6 mm