



Environmental problems and health risks with disposable baby diapers: Monitoring of toxic compounds by application of analytical techniques and need of education



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ABSTRACT

Due to the widespread use of disposable diapers in healthy babies as well as children prone to allergies and premature babies with reduced immunity, disposable diapers should only be made of non-toxic and natural ingredients. Unfortunately, disposable diaper manufacturers are reluctant to present their exact chemical composition, claiming that their trade secrets apply. However, several reports show that disposable diapers of well-known brands, "store" brands and "bio" brands may contain a number of toxic compounds. There is very little study focused on the chemical composition of disposable baby diapers. Commonly, diapers may contain different pollutants including polychlorodibenzo-p-dioxins (PCDDs), organically active compounds of ethylene benzene, xylene and toluene, polyacrylates or phthalates. Some of them may be risky for children's health. Only few methodologies are reported for the determination of some groups of compounds that could have a negative impact on the baby's skin condition. These procedures are mainly based on chromatographic separation. Another issue connected with disposable baby diapers is its enormous impact on the environment, starting from the production step, finishing at disposal procedure. Thus, the aim of this review is to present problems connected with disposable baby diapers and its impact on the baby's health and on the environment. One of the important issues in this range is the limited knowledge in society and this aspect is also described. Another topic discussed here is related to the occurrence of toxic compounds in disposable baby diapers. Moreover, the importance of analysis and monitoring of these xenobiotics is reviewed in the article.

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1. Introduction

The newborn's health is the most important aspect that the parents are worried about, if this issue was neglected, the results would be inconvenient. Babies have different needs connected with the proper everyday life hygiene such as nutrition or care [1–3]. One of the accessories necessary for babies is an appropriate diaper. There is a wide choice of sanitary napkins, however a model chosen

for a baby should not only be comfortable but also should guarantee health [4,5]. Typically, diapers are used in direct contact with the skin, 24 h a day, 7 days a week. As a consequence, any chemicals implied in diapers will affect the baby's body and, therefore, health [6]. In addition, frequent use of diapers by children who do not control micturition, impact on the environment, starting from the production step, finishing at disposal procedure. Thus, as a result the following issues are connected with the application of disposable baby diapers: environmental problems, health risks, monitoring of toxic compounds occurrence in these goods and the need for education in this area. What is needed is a research-based, evidence-based education with precise advice and guidance on how to proceed. The recipients of this type of training should be broadly understood guardians of children: from health care workers to

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Abbreviations:

ADL	acquisition and distribution layer	GC-FPD	gas chromatography–flame photometry detector
AMPA	aminomethylphosphonic acid	HPLC	high performance liquid chromatography
BBP	Benzyl butyl phthalate	HRGC-MS	high resolution gas chromatography mass spectrometry
BTEX	benzene; ethylbenzene; toluene; xylenes	HS	headspace technique
BTHs	benzothiazoles	LC-MS/MS	liquid chromatography–tandem mass spectrometry
BPA	bisphenol A	LDPE	low-density polyethylene
BTRs	benzotriazoles	LOD	limit of detection
DBP	Dibutyl phthalate	LOQ	limit of quantitation
DBT	Dibutyltin	LR	linear range
DCM	dichloromethane	MS	mass spectrometry
DEHP	Diethylhexyl phthalate	MSPE	Magnetic solid-phase extraction procedure
DEP	Diethyl phthalate	NaBEt ₄	sodium tetraethylborate
DMP	Dimethyl phthalate	PAHs	polycyclic aromatic hydrocarbons
DOT	Dioctyltin	PCBs	polychlorinated biphenyls
DPB	Dibutyl phthalate	PCDDs	polychlorodibenzo-p-dioxins
EC	elimination communication	PCDFs	polychlorodibenzo furans
ECF	Elemental chlorine free	SIM	selected ion monitoring
ED-XRF	energy dispersive X-ray fluorescence	SPE	solid phase extraction
EU	European Union	TBT	Tributyltin
FID	flame ionization detector	TeBT	tetrabutyltin
FOMOC	9-Fluorenylmethyl chloroformate	TOT	trioctyltin
GC	gas chromatography	TPT	triphenyltin
		UAE	ultrasound-assisted extraction

parents. Whereas the health of newborns, it is obvious that diapers should be made of non-toxic ingredients. However, recent reports show that diapers can contain many toxic substances [7–9], and here, several questions came to mind:

1. Are baby disposable diapers safe for babies considering its chemical characterization?
2. Are there toxic compounds presented in disposable baby diapers? If so, do we know them and the level of their occurrence?
3. Is the chemical composition of disposable baby diapers monitored? If so, which methodology is used for these purposes?
4. Does universal analytical methodology applied for the evaluation of the possible toxic compounds occurring in disposable baby diapers exist?
5. What about the toxic compounds that could be present in disposable baby diapers and their release into the environment?
6. Are environmental impacts related to disposable baby diapers assessed?
7. Are the key areas of improvement of environmental impacts related to disposable baby diapers identified?

There is very little study focused on the chemical composition of disposable baby diapers and this is why it is hard to provide answers for given questions. However, it is known that diapers contain a high variety of chemicals; some of them can pose a threat to the babies' health [10]. Any chemical contained in the diaper can cause skin dermatitis [2]. However, extensive research on these compounds used in them, such as polyacrylates, or phthalates or diethylbenzene show carcinogenic effect [11,12].

Only few methodologies are reported for the determination of some groups of compounds that could have a negative impact on the baby's skin. These procedures are mainly based on application of chromatographic instruments like gas chromatography (GC) and high performance liquid chromatography (HPLC) which are used for prepared sample by using the proper extraction methodology (this can differ depending on the analytes chemical groups). Due to the fact that the chemicals presented in disposable baby diapers

occur at very low value, the limits of detection of chromatography instruments are not low enough for the determination of these analytes in a direct way. In addition, the determination of target compounds is also problematic due to the occurrence of the large concentrations of unwanted compounds in the sample matrix. To minimize these problematic issues, the analytical protocol must incorporate sample pretreatment stage including preconcentration and separation steps to free these analytes from the matrix components.

The aim of this review is to present problems connected with disposable baby diapers and its impact on the baby's health and on the environment. One of the important issues is insufficient knowledge among the public in this regard. Another aspect discussed here is related to the occurrence of toxic compounds in disposable baby diapers. The importance of analysis and monitoring of these xenobiotics are mentioned. The lack of accurate information on the occurrence of various types of chemical compounds in disposable baby diapers, the insufficient knowledge on the concentration levels at which they occur and, moreover, the limited number of analytical methods that would be used to determine and monitor these toxic compounds have become a significant motivation to address this problem.

2. Toxic compounds in disposable baby diapers: analysis and monitoring

Disposable baby diapers are among the most important baby accessories, which improve the lives of parents in most countries of the world. It was estimated that about 4600–4800 diapers are used during the first three years of a baby's life [13]. Disposable diapers are supposed to absorb and retain the faeces and urine while keeping the baby's skin clean and dry. This is possible due to multilayer diaper construction (Fig. 1).

The main source of toxic compounds in diapers is raw-material contamination (e.g. herbicides or pesticides), inappropriate materials used for the diapers production and materials used for the layer connections, or manufacturing processes [17]. For example, PCBs,

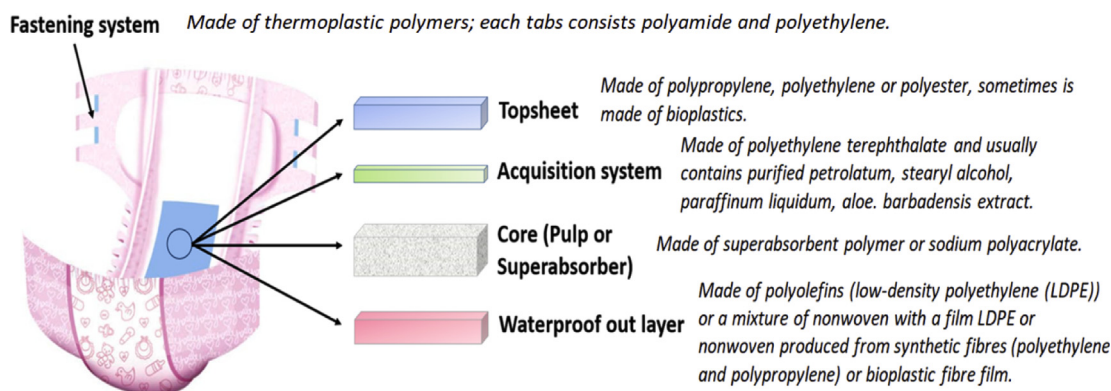


Fig. 1. Diagram of a disposable baby diaper's construction [13–16].

PCDDs and polychlorodibenzo furans (PCDFs) are formed as a result of cellulose bleaching. There are currently few bleaching methods, however, a process based on chlorine dioxide is the most popular. The elemental chlorine free (ECF) method reduces the quantity of chlorinated products but does not eliminate them. The possible source of nonylphenol is nonylphenoethoxylates which is used as surfactant for cleaning, surface treatment, emulsification, or solubilisation. Caprolactam comes from nylon threads and poly(etheramide) elastomers. The source of the abietic acid and dehydroabietic acid can be glue used for diapers [18]. PAHs are mainly found in elastics and probably can be formed during the manufacture of diapers due to the use of high temperatures manufacturing processes [17].

2.1. Application of analytical procedures to determine and monitor xenobiotics in disposable baby diapers

Due to the presence of toxic compounds in diapers and their possible negative effect on babies' health, it is necessary to control the content of individual compounds in diapers. However, there are a very limited number of papers devoted to the identification of toxic compounds and methods that allow to determine them in diapers. Nevertheless, there is a lack of studies devoted to the simultaneous determination of several groups of specific toxic compounds, and there are not specific analytical studies for this particular product: the disposable baby diapers. Most literature only includes aspects related to allergies, occurrence of enteric pathogens [19], or identification of toxic compounds in urine extracted from diapers absorbers [20,21] and only few studies include the determination of a selected compound in part of diapers [22]. This is why our group would like to focus on this topic and motivate for future research.

The published articles focused on the analysis of selected toxic compounds in disposable baby diapers are based on the chromatographic techniques i.e. HPLC or GC (Table 1). However, as the toxic compounds presented in disposable baby diapers occurred at very low value, the detection limits of a chromatography instrument coupled to a selected detector are not small enough for the straight determinations in sample solutions. Another issue may be related with the huge concentrations of unwelcomed resources in the matrix. To diminish such problems, the study must include preconcentration and separation stages to free these analytes from the matrix components. Moreover, high concentrations of matrix constituents, with the acids used for sample dissolution or digestion can bring inaccuracies in a method. For these reasons, advanced separation methods following microextraction procedures would be recommended to meet these needs.

Most of the analytical procedures have been developed for the studies of phthalate content in baby diapers so far. Due to the relatively volatile nature of phthalates, GC in combination with a mass spectrometry (MS), or a flame ionization detector (FID) is most often used to identify and quantify them in the individual parts of the diapers. However, due to the rather complex composition of the individual diaper layers, the MS detector in selected ion monitoring (SIM) mode is preferred for the determination of phthalates [23,24]. Only in one article, detector FID was used [22]. In some reports, the phthalate content of diapers was determined using the ISO 8124–6:2018 standard method [25,26]. In this method, 1 g of the sample is used for a Soxhlet extraction with DCM as a solvent and analyzed by GC-MS. However, the extraction procedure is time-consuming as it takes 6 h and requires large amounts of toxic solvents. Additionally, this method is not dedicated to studying phthalate content in diapers but to testing toys (“ISO 8124–6:2018, Safety of toys — Part 6: Certain phthalate esters in toys and children’s products,”). Therefore, it is better to apply special procedures designed to study phthalates in baby diapers. In one of these procedures, the ultrasound-assisted extraction (UAE) with dichloromethane (DCM) as a solvent was successfully used for the isolation and enrichment of phthalates. The application of the sonication in the extraction procedure made it possible to obtain low limits of quantitation (LOQ) values (below 1 µg/g). Using this procedure, in the top sheet layer of diapers from Japan, two phthalates including DEHP and DBP were identified in the concentration range of 0,1–0,6 and 0,1–0,2 mg/g, respectively [23]. The similar procedure was also used for the determination of phthalates and pesticides in diapers from Belgian market [26]. In other studies, magnetic chitosan coated with polyaniline (Fe₃O₄@CHI@PANI) was used as a sorbent in magnetic solid-phase extraction procedure (MSPE). In this method, 0.1 g of the top-sheet layer of the diaper was mixed with HCl and placed in an ultrasound bath, and diluted with deionized water. The liquid sample was added to magnetic sorbent in the vial, and stirred. The magnetic nanoparticles were successfully enriched with phthalates, due to π–π interaction between the polyaniline shell and aromatic ring of phthalates. The use of the MSPE-GC-FID method enables the determination of low concentration phthalates (LOD: 0.2–0.5 µg/L) in baby diapers. Four of them i.e. DMP, DBP, BBP, DEHP in concentrations ranging from 86.4 to 1440 µg/g have been detected in Iranian diapers [22]. The procedures based on MSPE, were better than those based on UAE in respect to lower LOD, number of analytes detected and less toxic solvents used. However, even better results in these aspects were obtained by application of liquid chromatography-tandem mass spectrometry (LC-MS/MS) with a combination of solid-liquid extraction (SLE). To measure phthalate contents, about 1 cm² of a single pad of the diaper section was transferred to the vial with

Table 1

Information on the group of xenobiotics determined in disposable baby diapers together with characterization of the analytical procedures used to their determination.

Group of xenobiotics	Impact of xenobiotics on baby's health	Analyzed part of diapers	Sample preparation method	Apparatus	LOD, LOQ, LR	Identified xenobiotics	Method remarks	Ref.
phthalates	May cause an allergic skin reaction and they act as endocrine disruptors.	topsheet	UAE (extraction solvent: DCM)	GC-MS (SIM mode)	LOD: n.d. LOQ: 0.1–1 µg/g LR: n.d.	DEHP: 0.1–0.6 µg/g DBP: 0.1–0.2 µg/g	- requires application of toxic solvents; - no data on extraction time and volume of extraction solvent;	[23]
		topsheet	UAE (extraction solvent: DCM)	GC-MS	LOD: 0.0033–0.067 mg/kg LOQ: 0.01–0.2 mg/kg LR: 0.015–2 µg/mL	DBP: 0.16 mg/kg DEHP: 0.4 mg/kg	- time-consuming procedure (2 h) - requires large amounts of DCM (150 mL);	[26]
		topsheet	MSPE (Sorbent: Fe ₃ O ₄ @CHI@PANI; desorption solvent: ethyl acetate)	GC-FID	LOD: 0.2–0.5 µg/L LOQ: n.d. LR: 1–2000 µg/L	DMP: 86.4–1440 µg/g DBP: 147.5–648.1 µg/g BBP: 100.8–720 µg/g DEHP: 86.5–1224 µg/g	- lower LOD, number of analytes detected in comparison to UAE extraction; - less toxic solvents; - short sample preparation time	[22]
		whole diaper	SLE (extraction solvent: methanol/water; 80/20%)	LC-MS/MS	LOD: n.d. LOQ: 0.1 ng/mL for DBP, DEHP, DEP; and 0.05 ng/mL for BBP LR: n.d.	DEHP: 12.6–62.8 ng/mL DBP: 13.4–1609.7 ng/mL DEP: 0.8–2.9 ng/mL	- short extraction time (15 min); - better results can be obtained by application of SLE with combination of LC-MS/MS.	[27]
total residual acrylic acid	Adverse skin, eye, and throat reactions	superabsorbent polymer	HS (reacting agent: bicarbonate)	GC-TCD (CO ₂ was measured)	LOD: 124.3 µg/g LOQ: 373 µg/g LR: n.d.	n.d.	- simple extraction procedure, which prevents the introduction of non-volatile substances into the GC instrument; - there is not possible to the determination of individual total residual acrylic acids in diapers; - high LOD.	[29]
Monoaromatic hydrocarbons	Irritation and defatting after prolonged or repeated contact with the skin. Redness and blisters may occur. Possible endocrine distribution	whole diaper	HS	GC-MS	LOD: n.d. LOQ: 0.001 ng/mL LR: n.d.	toluene: 0.102–0.397 ng/mL o-xylene: 0.005–0.021 ng/mL m-xylene: 0.002–0.013 ng/mL p-xylene: 0.003–0.01 ng/mL	- simple extraction procedure, which prevents the introduction of non-volatile substances into the GC instrument;	[27]
		topsheet	HS-UAE (extraction solvent: methanol)	GC-MS	LOD: n.d. LOQ: 0.1 mg/kg LR: 0.4–7 mg/kg	All identified compounds were below the LOQ	- low LOQ of BTEX - In comparison to conventional HS, HS-UAE requires	[26]



organotIONS	OrganotIONS have a variety of toxicity, including immunotoxicity, and effects on the nervous system	diaper cover	SLE (extraction solvent: <i>tert</i> -butyl ethyl ether; derivatizing agent: NaBEt ₄)	GC-FPD	LOD: 2.7–9.7 ng/g LOQ: 8.1–29.1 ng/g LR: 0.01–0.20 µg/mL	DBT: 0.24 µg/g TeBT: 0.013 µg/g DOT: 0.65 µg/g TOT: 0.051 µg/g	<ul style="list-style-type: none"> - application of toxic solvents (200 mL of methanol), without a significant improvement in the sensitivity of the method. - derivatization step is required; - application of specified detector (FPD) limits peaks co-elution; - low LOD 	[30]
		topsheel	SLE (extraction solvent: CH ₂ Cl ₂ , derivatizing agent: NaBEt ₄)	GC-FPD	LOD: 0.3–10 pg LOQ: 0.9–30 pg LR: n.d.	DBT: 177 µg/kg TBT: 98 µg/kg	<ul style="list-style-type: none"> - derivatization step and toxic extraction solvent are required; - application of specified detector (FPD) limits peaks co-elution; - low LOD 	[31,32]
		Top sheet and adhesive tape system	–	ED-XRF	LOD: 1.5 mg/kg LOQ: n.d. LR: 1.5–60 mg/kg	Sum of organotIONS in topsheel 2–23 mg/kg; in adhesive tape system 9.5–22.4 mg/kg	<ul style="list-style-type: none"> - non-destructive procedure, - requires less sample preparation step and time, - derivatization procedure is not required; - a non-homogenous sample can be analyzed. - high detection limit; - only total content of organotin can be analyzed in a large sample volume, 	[33]
formaldehyde	Formaldehyde has been linked to cancer, skin irritation, and skin allergies.	Lining and waterproof layer	SLE (water at 40 °C, derivatizing agent: 2,4DNPH)	HPLC-UV	LOD: 0.004 mg/kg LOQ: 0.011 mg/kg LR: n.d.	Formaldehyde in lining: 0.011–45 mg/kg Formaldehyde in waterproof layer: 0.13–15.42 mg/kg	<ul style="list-style-type: none"> - derivatization step is required; - non-toxic extraction solvent is used (water); 	[35]
benzothiazoles	Benzothiazoles are classified as probably carcinogenic to humans.	whole diaper	UAE (extraction solvent: AC:DCM in 1:4 v/v)	HPLC-ESI-MS/MS	LOD: 0.7–4 ng/g LOQ: 2.1–12 ng/g LR: 0.2–200 ng/mL	BTHs: 16.6 ng/g	<ul style="list-style-type: none"> - requires mixture of toxic solvents (10 mL of solvent mixture); 	[36]

(continued on next page)

Table 1 (continued)

Group of xenobiotics	Impact of xenobiotics on baby's health	Analyzed part of diapers	Sample preparation method	Apparatus	LOD, LOQ, LR	Identified xenobiotics	Method remarks	Ref.
biocides, phenolic compounds, parabens, caprolactam, and pentadecafluorooctanoic acid (PFOA)	Estrogenic effects, and skin irritation	Top sheet	UAE (extraction solvent: methanol)	HPLC-ESI-MS/MS	LOD: 3.3 µg/kg LOQ: 10 µg/kg LR: 6.3–65 µg/kg	Nonylphenol: 38–4400 µg/kg Caprolactam: 29–590 µg/kg	- relatively short extraction time (20 min). - relatively time-consuming procedure (ultrasonication for 1 h, followed by 1 h shaking); - requires large of toxic solvent (200 mL);	[26]
bisphenols, benzophenones, and bisphenol A diglycidyl ethers	They can have an impact on the brain and prostate gland, and children's behavior.	whole diaper	UAE (extraction solvent: AC:DCM in 1:4 v/v)	HPLC-ESI-MS/MS	LOD: 0.033–1.67 ng/mL LOQ: 0.1–5 ng/mL LR: 0.74–14.7 ng/g	BPA: 37.7 ng/g 3R-NOGE: 3.57 ng/g	- toxic solvents are used (10 mL); - short time of extraction procedure (20 min).	[41]
PCDDs	May cause skin disorders, liver problems, impairment of the immune system, the endocrine system and reproductive functions, effects on the developing nervous system and other developmental events. Certain types of cancers.	Cotton (textile) part of diapers	Soxhlet extraction (extraction solvent: 500 mL mixture of hexane and DCM (1:1 v/v))	HRGC-MS	LOD: n.d. LOQ: 0.0016–1.3 ng/kg LR: n.d	2,3,7,8-TCDF: 0.051–0.17 ng/kg 1,2,3,7,8-PeCDF: 0.076 ng/kg 2,3,4,7,8-PeCDF: 0.056–0.06 ng/kg 1,2,3,4,7,8-HxCDF: 0.042–0.053 ng/kg 1,2,3,6,7,8-HxCDF: 0.043–0.18 ng/kg 2,3,4,6,7,8-HxCDF: 0.19 ng/kg 1,2,3,7,8,9-HxCDF: 0.065 ng/kg 1,2,3,6,7,8-HxCDD: 0.038 ng/kg 1,2,3,7,8,9-HxCDD: 0.085 ng/kg 1,2,3,4,6,7,8-HpCDF: 0.91 ng/kg	- time-consuming procedure (18 h) - requires large amounts of toxic solvents (500 mL of solvent mixture).	[37,38]
PAHs	Mutagenic and cancerogenic effects, endocrine distribution	Parts which are in contact with the skin of the baby	UAE (extraction solvent: acetone/n-hexane (20/80; v/v))	GC-MS (SCAN mode)	LOD: 0.02 mg/kg LOQ: 0.06 mg/kg LR: 0.02–4 µg/mL	All PAHs were below LOQ	- relatively time-consuming procedure (1–2 h); - requires large amounts of toxic solvents (200 mL of solvent mixture).	[26]
pesticides	May cause an allergic skin reaction and cancer.	Whole diapers without absorbents	UAE (extraction solvent: acidified water; derivatizing agent: FOMOC)	UPLC-MS/MS	LOD: n.d LOQ: 0.05 mg/kg LR: 0.005–0.25 mg/kg	glyfosaat: 0.072–0.13 mg/kg AMPA: 0.18 mg/kg	- relatively time-consuming procedure (1 h); - derivatization step is required;	[26]

1,2,3,4,6,7,8-HpCDF - 1,2,3,4,6,7,8-Heptachlorodibenzofuran; **1,2,3,4,7,8-HxCDF** - 1,2,3,4,7,8-Hexachlorodibenzofuran; **1,2,3,6,7,8-HxCDD** - Hexachlorodibenzo-p-dioxin; **1,2,3,7,8,9-HxCDD** - 1,2,3,7,8,9-Hexachlorodibenzo-P-dioxin; **1,2,3,7,8-PeCDF** - 1,2,3,7,8-Pentachlorodibenzofuran; **2,3,7,8-TCDF** - 2,3,7,8-Tetrachlorodibenzofuran; **2,4DNPH** - 2,4-dinitrophenylhydrazine; **3RNOGE** - novolac glycidyl ether 3-ring; **PCB-81** - 3,4,4',5-Tetrachlorobiphenyl; **PCB-77** - 3,3',4,4'-Tetrachlorobiphenyl; **PCB-123** - 2,3',4,4',5'-Pentachlorobiphenyl; **PCB-118** - 2,3',4,4',5'-Pentachlorobiphenyl; **PCB-114** - 2,3,4,4',5-Pentachlorobiphenyl; **PCB-105** - 2,3,3',4,4'-Pentachlorobiphenyl; **PCB-167** - 2,3',4,4',5,5'-Hexachlorobiphenyl; **PCB-156** - 2,3,3',4,4',5-Hexachlorobiphenyl; **PCB-157** - 2,3,3',4,4',5'-Hexachlorobiphenyl.

LOD – limit of detection; LOQ – limit of quantitation; LR – linear range; n.d. – not described.

appropriate solvent - 80 % methanol (v/v) and shaken. In diapers at the highest concentrations, DBP and DEHP were detected in concentrations in the range of 12.6–62.8 and 13.4–1609.7 ng/mL, respectively [27]. Considering limited data focused on the method for phthalates determination in baby diapers, it could be stated that development of new analytical protocols is still required. These protocols should base on microextraction techniques that allow to determine trace amounts of phthalates in diapers. In addition, it would be great to minimize aliquots of solvents used, thus, GC-MS would be a preferable choice.

Most of the analytical procedures for the determination of volatile organic compounds, i.e. monoaromatic hydrocarbons (benzene; ethylbenzene; toluene; xylenes, BTEX), chlorine compounds, organotin compounds (tributyltin, TBT; triphenyltin, TPT; Dibutyltin, DBT; tetrabutyltin, TeBT; trioctyltin, TOT; Dioctyltin, DOT) in disposable baby diapers are based on the use of static headspace technique (HS) combined with GC. The HS is preferred as an isolation and enrichment step because it is simple, prevents the introduction of non-volatile substances into the GC equipment, and enables the determination of various volatile organic compounds in many matrices i.e. different types of disposable baby diapers layers [28]. The HS-GC procedure was successfully used for the determination of total residual acrylic acid in superabsorbent polymers after reacting with bicarbonate [29] and monoaromatic compounds [27] in a selected part of disposable baby diapers. However, in order to determine monoaromatic compounds at lower concentrations, a better solution is to use an ultrasound-assisted extraction with 200 mL of methanol followed by headspace analysis (HS-UAE). This method allows the identification of BTEX as well as styrene and alpha-methylstyrene at a concentration of 0.1 mg/kg [26].

For the determination of organotin compounds, the procedure based on GC coupled to flame photometric detector (GC-FPD) following liquid/liquid partitioning with *tert*-butyl ethyl ether after reflux-extraction was proposed [30]. For the reflux-extraction the methanol containing 1 % (v/v) of hydrochloric acid and *tert*-butyl ethyl ether were used followed by a derivatization procedure using sodium tetraethylborate (NaBEt₄). These procedure allows the simultaneous determination of hydrophobic organotin compounds i.e. TBT and slightly less hydrophobic DBT at low concentration level. The limits of detection were 2.7–9.7 ng/g. Using the described method, DBT (0.24 µg/g), TeBT (0.013 µg/g), DOT (0.65 µg/g), TOT (0.051 µg/g) were detected in a diaper cover [30]. In other similar procedures [31,32], the top sheet layer DBT and TBT were identified at concentrations of 177 µg/kg and 98 µg/kg, respectively. A completely different procedure based on radioisotope (americium) excited energy dispersive X-ray fluorescence (ED-XRF) was proposed by Śmajgl and Obhodaš [33]. In comparison with conventional chromatographic methods, the application of ED-XRF has some advantages i.e. is non-destructive, requires less sample preparation step and time, the total content of organotin in baby diapers can be analyzed in a larger sample volume, non-homogenous sample can be analyzed and derivatization procedure is not required. However, the limitations are in a relatively high detection limit of 1.5 mg/kg and the possibility of determining only the sum of organotin compounds. In these studies, the highest concentration of organotins found in the adhesive tape and top sheet of disposable baby diapers was 22.4 and 23.1 mg/kg, respectively.

For the determination of formaldehyde in disposable baby diapers, Liou et al. [34] proposed a simple screening procedure based on chromotropic acid method. In the presented studies, 1²-in of diaper was placed in the bottle with an open vial of mixture consisting of 4 mg chromotropic acid and 1 mL of sulfuric acid. As a result of the reaction of chromotropic acid with free formaldehyde in an acidic environment, the purple discoloration was observed.

The LOD of the procedure was 2,5 mg/kg. However, to determine the exact concentration of formaldehyde in baby diapers, more advanced analytical methods are needed. One of the described procedures is based on SLE with water at 40°C as an extraction solvent followed by derivatization using 2,4-dinitrophenylhydrazine (2,4DNPH) and analyzed at 354 nm using HPLC-UV can be used. The application of this method allowed the detection of formaldehyde in 27 out of 45 tested diaper samples. Depending on the tested layer, the concentration of formaldehyde was in the range of 0.011–45 and 0.13–15.42 mg/kg for lining and waterproof layer, respectively [35].

Benzothiazoles (BTHs) and benzotriazoles (BTRs) can be measured in disposable baby diapers by means of UAE extraction with a mixture of acetone: DCM in 1:4 vol ratio with combination of HPLC-ESI- MS/MS. This procedure allows the determination of BTHs and BTRs at low concentration level (LOD: 0.7–4 ng/g) in textiles products. In disposable baby diapers from various retail stores and supermarkets in Albany, New York, USA, the mean concentration of BTHs was 16.6 ng/g [36]. The method based on UAE with methanol as extraction solvent, followed by HPLC-ESI-MS/MS can also be used for the content examination of biocides, phenolic compounds, parabens, caprolactam and pentadecafluorooctanoic acid (PFOA) in topsheet layer of diapers. In one report, among twelve tested xenobiotics, nonylphenol and caprolactam were identified at the highest concentration ranging from 0.038 to 4.4 mg/kg, and 0.029–0.59 mg/kg, respectively [26]. The similar procedure was used for the identification and determination of BTH and BTR in textiles infants. In the diapers The novolac glycidyl ether 3-ring (3RNOGE) and bisphenol A (BPA) was identified in diapers at concentration of 3,5 and 37,3 ng/g, respectively [36].

Typical procedure used for the determination of PCDDs in hygiene products is based on Soxhlet extraction, followed by solvent evaporation and purification on acid silica, then on a multilayer silica column and then on alumina. High resolution gas chromatography mass spectrometry (HRGC-MS) is mainly used for the quantitative analysis of PCDDs [37]. The procedure is analogous to that described in EN 16190:2018 norm [38]. A total of ten PCDDs have been identified using the described method in the cotton or textile part of disposable baby diapers from Belgian market at concentrations ranging from 0.038 to 0.91 ng/kg [26].

Another important group of compounds with carcinogenic properties are PAHs, which can be determined using gas or liquid chromatography [39,40]. Despite the very negative impact of PAHs on the health of infants, only one report presents the procedure of their determination in diapers. In the presented procedure, only elements having direct contact with the skin were analyzed. PAHs extraction was performed using the UAE method with acetone/n-hexane (20/80; v/v). In the next step, extract was purified by means of silica/alumina column followed by evaporation and concentrated [26]. The same report also describes the procedure for determining glyphosate and its major metabolite, aminomethylphosphonic acid (AMPA). In the described method 10 g of a diaper (without absorbent materials) were extracted using UAE with 200 mL of acidified water. Then 10 mL of extract were mixed with 6 M potassium hydroxide, borate buffer and 9-Fluorenylmethyl chloroformate (FOMOC) as derivatization reagent. After the derivatization step, formic acid, water and EDTA were added to the liquid sample. At the end, a solid phase extraction (SPE) clean-up procedure was performed, and the sample was analyzed by means of UHPLC-MS/MS equipment.

Considering the health problems of baby's related to the wearing of diapers, it could be concluded that there is a great need to develop new procedures for all groups of the compounds mentioned here. It would be desirable, if one protocol was used to

separate different groups of analytes and determine them at trace level. Eco-friendly methodologies are highly recommended, thus, in our opinion microextraction techniques should be applied during the sample preparation step. However, some problems with the determination mentioned here organic analytes at trace level can be expected. It is connected with contamination during each stage of the analytical procedure from sampling to sample preparation up to chromatographic analysis. This often leads to false-positive or overestimated results. Another problem associated with determination of mentioned analytes occurs at trace- and ultra-trace level can be a background problem (e.g. for phthalates, bisphenols or benzophenones) which is mainly dictated by techniques, glassware and solvents. This is why error sources in the field of determination of trace analytes should be found and eliminated.

Additional remarks are connected with the parts of the diaper which should be analyzed. It would be good to apply the developed procedure to each part of the diaper, but also to the whole diaper. Only in such a way, representative information will be given.

3. Disposable baby diapers and problems related with their use: insufficient knowledge in society and need of education

In the past years, the advance of technology designed disposable diapers, which provide better skin protection, dryness and less leakage. However, health professionals have used tradition and personal experience to guide women as there has been, until recently, little robust research, and synthesis to guide practice in safe and effective baby skin care. Often cultural, social and economic factors influence practices rather than clear and cohesive link between scientific data and interpretation.

African studies found that traditional factors influence diaper practices such as applying ash, powders made of roots, burnt gourds or cooking oil that may be harmful to the baby skin as well as frequent baby bathing [42]. Lack of analysis and integration of research-based and practice-based knowledge may lead to repetitive and sometimes risky care practices. One of the common health problems causing considerable pain and stress for infants, connected with diaper usage, is a diaper (nappy) rash or diaper dermatitis [5,14]. It is a flammable, episodic reaction lasting 2–3 days, typical for infants' ages 9–12 months. Severity of the skin irritation can be wide in scale from mild dryness, a few scattered papules to very intense redness or even edema, severe desquamation, erosion and ulceration. Common types of diaper dermatitis are chaffing dermatitis, irritant contact dermatitis and diaper candidiasis [43–45]. Good hygiene practices and regular diaper changes can reduce the frequency of developing nappy rash, but cannot eliminate it [46,47]. The causes of diaper dermatitis are multifactorial (chemical, physical, enzymatic, microbial factors) and are largely not related to the diaper itself. The pH of the skin can be increased by a mixture of urine and feces, which can lead to break down of the protective lipids and proteins in the stratum corneum. If a soiled diaper is not changed immediately, it can activate fecal enzymes that can contribute to skin irritation in typical anatomic areas (e.g., genital, perianal) [10]. Therefore, proper diapering hints, behavior change, knowledge promotion and basic parental education are keys to success. Proper training and education should be targeted to wide audiences including hospitals, health professionals, parents and service providers where clear evidence-based advice and guidance is conveyed.

Other problems associated with disposable baby diapers are environmental issues. It has been estimated that nowadays, more than 95 % of families in Europe use disposable diapers for their babies. In another report made by the Environment Agency, it has been noted that babies are using an average of 4.16 disposable diapers per day. Considering 2,5 year of diapering, this corresponds to

a consumption of 3796 units during this period for one baby, which gives almost 21 billion baby diapers consumed annually in the European Union (EU) alone [10]. In the United States the problem is similar, there are about 4 million babies born every year. These babies use about 2500 diapers during their first year of life. Thus, it can be calculated that from babies under one year old, around a trillion diapers a year are disposed of by Americans. And nor, taking into account all kids before potty-training age, the amount grows. It has been proved that kids in their second year of life require around 4–5 diapers per day which gives an extra 1400–1800 diapers a year, per kid. Disposable baby diapers have an enormous impact on the environment, starting from the production step, finishing at disposal procedure. During the step of getting the raw materials such as pulp, cotton, plastics and the production of diapers, a huge amount of wastewater is produced.

They contain priority pollutants and compounds which are considered hazardous, including PCDDs, PCDFs and chlorophenols, solvents, sludge and additional heavy metals. Release of effluents from these industries has resulted in significant environmental degradation. It also needs to be known that during the production processes but also the process of application, distribution and disposal of diapers, harmful substances are released into the air. The air pollution from the production of disposable baby diapers is very noxious due to the fact that it includes dangerous chemicals including sodium polyacrylate, chlorine, PCDDs, TBT that are released into the environment.

Additional factors must be also taken into consideration. Disposable baby diapers represent an incredible amount of environmental waste [8]. Another problem is that after diapers end up at landfills, they stay there for a long time. This is due to the fact that they are composed of the plastic and super-absorbance gel and it takes hundreds of years for them to decompose when exposed to sunlight and air. Without sun and air, even so-called “eco-friendly” diapers labeled biodegradable do not biodegrade in landfills, and cause just as much of a problem as regular diapers [48].

Another problem connected with the diapers is that not only the diaper product is disposed of in the landfill, but untreated feces and urine as well. Parents are not educated in this area that waste from diapers should be cleaned and down the toilet. Appropriate approach of diapers usage also means their correct storage after use and disposal. It is documented that human feces can leach and cause contamination. In addition, they can spread communicable diseases when disposed of in the landfills [49]. Vaccines given to newborns may be partially excreted with the faeces. Therefore, excrement can be a breeding ground for a wide variety of viruses, including Hepatitis B and polio. This is why there are printed hints on the side of most disposable diaper packages instructing caregivers to rinse the diaper and flush the fecal material down the toilet before putting it into the trash, yet, rarely, if at all followed.

Additional problem is that during the decomposition of disposable diapers methane is released in the air. It is a greenhouse gas that replaces oxygen and which, from billions of diapers thrown away, significantly contributes to global warming.

Assuming the average baby will use 4000 disposable diapers, several factors that impact on the environment must be considered (Fig. 2).

4. Conclusions and future perspectives

In today's world, the possibility of using disposable diapers is associated with a significant improvement in family life. However, the production and further diaper disposal procedure negatively affects the environment. Additionally, in some commercially available diapers xenobiotics compounds can be found (i.e. organotin, pesticides, PAHs, PCDDs, bisphenols, benzothiazoles,

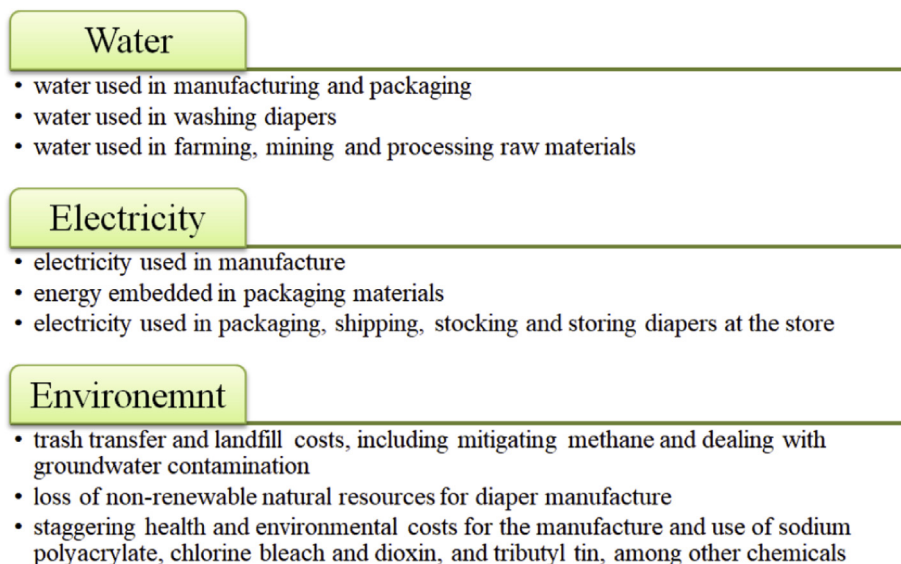


Fig. 2. Factors that should be considered in the connection with disposable baby diapers and environment.

monoaromatic hydrocarbons, phthalates) which can have undoubtedly a negative impact on the health of the infants. Currently, very few studies and reports confirm the above observation. Research on the content of toxic compounds in diapers has been done in only a few countries. Therefore, it is not known what the situation is in other countries and whether the problem of xenobiotics in disposable diapers is a global problem. Undoubtedly, much larger-scale research is needed. At present, in most countries, there are no legal regulations that would define the maximum permissible concentration of individual xenobiotics in diapers. Hence, there are also no universal methods of determining them, and only a few publications can be found on this subject.

As the toxic compounds presented in disposable baby diapers occurred at very low value, the LOD of analytical apparatus are not low enough for their direct determinations in real sample solutions. The second problem is the occurrence of numerous chemical compounds with different concentrations in the matrix, which may cause inaccuracies in a method. In order to minimize the above problems, the analytes preconcentration and separation steps should be applied. Without any doubt, it is recommended to work in this area, as there is a limited number of analytical methods that would be used to determine and monitor the toxic compounds. The methods developed so far for the determination of xenobiotics in disposable diapers consist of the use of chromatographic techniques. In available procedures, before chromatographic analysis, samples are prepared using various extraction techniques (i.e. UAE, MSPE, SLE, Soxhlet), which require the use of large amounts of toxic organic solvents (i.e. DCM, acetonitrile, n-hexane, acetone, methanol), and also reagents for derivatization. In the near future, the currently used extraction methodologies will probably be replaced by new, more effective procedures involving the use of small amounts of “green” solvents, such as ionic liquids or deep eutectic solvents. On the one hand, the developed extraction methods shall prevent the negative impact of the laboratory in which the analyses are performed on the environment, minimize the matrix interferences, and allow the determination of xenobiotics in diapers at much lower concentration levels. On the other hand, the constant development of research apparatus should help to lower the detection limits of individual xenobiotics, and also enable the determination of many toxic substances during one analysis. In addition, most of the presented analytical methods are dedicated to

the determination of xenobiotics in the selected part of the diaper. There is still a lack of methods that can monitor toxic components in whole diapers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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