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Use of fluoropolymers in chemical manufacturing plants

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1. Executive Summary

As indicated in Table A.1. of Annex A of the restriction proposal, the PFAS applications in the chemical industry were not researched in detail during the preparation of the proposal. As a result, the use of fluoropolymers in chemical industry was not considered as a derogation.
In order to support the authorities with their evaluation, we provide substantial data on

- the indispensable need of fluoropolymers in chemical production (for details, see chapters 2.1 - 2.3),
- the chemical resistance and leaching behavior of PTFE (for details, see chapter 2.4)
- the incompatibility/lack of non-PFAS alternatives (for details, see chapter 2.4),
- the enormous impact of a potential ban, due to the ubiquitous presence of fluoropolymer components in production equipment (for details, see chapter 2.1),
- the range of PFAS emissions resulting from the use of fluoropolymers in production, namely:
    - information on the very low turnover and disposal volumes of fluoropolymers (for details, see chapter 3),
    - information on the disposal of our fluoropolymer components at a hazardous waste incineration plant (for details, see chapter 4),
- the immense potential impact on our company (for details, see chapter 5).

Considering the evidence provided, we ask for a time-unlimited derogation for the use of fluoropolymer materials in chemical manufacturing. This derogation must include all upstream processes to manufacture these fluoropolymers and articles to ensure resilience of the chemical industry in the EU market.

The restriction proposal contains a list of applications for which temporary exemptions are considered, but the use of fluoropolymers in chemical industry production has not been taken into account.

Industrial chemical manufacturing is highly integrated, often including multiple process steps, and using multipurpose facilities/plants. Fluoropolymers and other PFAS-containing articles are uniquely suited for use in these production steps. Use of these materials is critical due to their unparalleled chemical and permeation resistance, chemical durability, temperature stability and low leaching potential.

The restriction proposal in its current form would inevitably jeopardize the functioning of the European chemical industry, and critically impact downstream use sectors, such as the semiconductor and pharmaceutical industries.

Taken together, the use of PFAS in manufacturing plants is understood as essential to the chemical industry. The proposed ban will negatively affect its current innovative strength and the desired resilience of European industry.

Fluoropolymer components are used in chemical manufacturing facility equipment and infrastructure numbering in the many thousands. In order to bring clarity, we provide concrete examples of production usage in chapters 2.1 and 2.2..

Non-PFAS alternatives cannot fulfil the specific application requirements and thorough testing of alternatives has so far not resulted in viable alternatives (see chapter 2.4) – which is based on the unique properties of the C-F-bond in PFAS materials.

The lack of alternatives exists for many of the industry's uses of fluorocarbon-containing articles and products and potential alternatives must be evaluated on a case-by-case basis.

With adequate risk management measures related to use and disposal of articles (including fluoropolymers), exposure to the environment or populations across all our product life cycle phases (service life, end-of-life, disposal) can be strongly limited.

The enormous impact of an implementation of the current draft restriction proposal on worker employment as well as on business figures of our company is described in a separate confidential document.

With the information provided we hope to contribute to an appropriate regulation of PFAS including fluoropolymers while avoiding critical impacts on EU industry. Given the broad range and complexity of PFAS uses in this area, we are open to a direct exchange allowing us to give more detailed insights – which also includes the option to visit our site in Darmstadt.

Additional comments will be submitted separately by Merck to provide also regarding other PFAS uses a better basis for an adequate regulation of PFAS materials.

Merck is additionally actively contributing to industry association comments as e.g. from VCI, Cefic, SEMI, SIA and EFPIA – some comments are already submitted, others will be submitted later in course of the consultation phase.

2. Demonstration of the need of fluoropolymers in chemical production

In the organization of Merck Electronics there are several plants on the company's site in Darmstadt, Germany.

We consider these plants as representative to show current fluoropolymer use in chemical plants using batch production and a broad set of organic solvents as well as strong acids or bases. These cases are representative to demonstrate why fluoropolymers materials are needed in such equipment.

By providing data on the (in)compatibility of different solvents with production materials we demonstrate that fluoropolymer materials are the only ones fulfilling the extreme needs in chemical manufacturing.

In addition to the manufacturing plants, fluoropolymers are also required in the packaging of some chemicals for a safe transportation.

To exemplify the practical relevance of fluoropolymers we selected one typical week of production/processing in three of our plants in our organization. In Table 1 the substance classes manufactured/processed are displayed including the respective solvents required. The substances manufactured/processed are for use in Electronic industry (OLED, liquid crystals, liquid crystal intermediate, chemical for semiconductor manufacturing), Pharmaceutical industry (intermediate for API, excipient for vaccine) and Cosmetic industry (cosmetic raw material).

Plant 1 is used for process developments and process optimizations. On average, plant 1 has a yearly turnover of about 1000 t of solvents. Plant 2 and plant 3 are larger scale production plants (for "fine chemical production dimensions").

Based on the solvents/starting materials/processing aids required for the production, the use of fluoropolymers is essential to provide the required chemical resistance and avoid product contamination. It should be noted that fluoropolymers are much more expensive than non-PFAS-components [see chapter 2.4]. Nevertheless, safety of workers and the environment as well as product quality, most of the times, require the use of fluoropolymers. Fluorine-free components are used, e.g., for packaging of (dry) starting materials/processing aids/products where no contact to, e.g., solvents is possible.

Table 1 Examples of productions/processing during one week in three plants each, in the organization of Merck Electronics

Plant	Substance class	Downstream use	Number of batches
1	OLED 1	Electronic industry	1
	OLED 2	Electronic industry	1
	OLED 3	Electronic industry	1
	Intermediate for API	Pharmaceutical industry	1
	Purification of a polymer for patterning process in semiconductor manufacturing	Semiconductor industry	3
2	OLED 4	Electronic industry	1
	Liquid crystal	Electronic industry	1
	Intermediate for liquid crystal	Electronic industry	1
3	Excipient for vaccine	Pharmaceutical industry	1
	Purification excipient 1	Pharmaceutical industry	3
	Purification of excipient 2	Pharmaceutical industry	6
	Cosmetic raw material	Cosmetic industry	2

In the following sections the manufacturing of each of these products is looked at in more detail regarding solvents used, processing temperatures and the respective compatibility to different materials – and information is given where respective components are used in the production equipment.

In the following chapters the compatibility of different materials is shown in "compatibility tables" as colored circles and a figure: a green circle with "1" means fully compatible, fully resistant, whereas yellow and red circles represent a partially or no resistance towards the solvent. The materials with other than green circles should not be used for a proper and safe handling of the equipment and product.

Blue colored materials in the compatibility table headers are different fluoropolymers; the green colored materials are “fluorine free materials”.

Basis for the conclusion on compatibility are information from DECHEMA Werkstofftabellen [https://dechema.de/dwt.html], information from material suppliers as well as internal data – which are also exemplarily shown in the following sections.

2.1. Solvents required for the manufacturing/processing in plant 1

As it can be seen in Table 2, almost exclusively organic solvents are required for the production/processing steps of the mentioned five products, e.g., anisole, ethanol, n-heptane, dichloro methane, tetrahydrofurane.

Table 2 Solvents used in the production/processing in plant 1

	Acetone	Acetnonitrile	Anisole	1-Butanole	t-Butyl methyl ether (10-50°C)	Cyclohexane	Dichloro methane	Ethanol	Ethyl acetate	n-Heptane (10-60 °C)	Methanol	2-Propanole (20-95 °C)	PGMEA	Sodium hydroxide solution (21-32 %, 50 °C)	Sodium hydrogen carbonate solution (20 °C)	Tetrahydrofurane	Toluene (0-110°C)	Water (20-50 °C)	Water/HCl (30 %; -10 - 50°C)
OLED 1			x					x										x	
OLED 2								x	x	x							x		x
OLED 3			x		x							x		x		x		x	
Intermediate for API	x						x				x					x		x	
Polymer for patterning process in semiconductor manufacturing		x				x			x				x			x		x	

2.1.1. Production of OLED 1: Presentation of compatible materials for the production equipment and implementation in the production

Based on the solvents required, the materials in the production equipment have to be chosen.

Table 3 shows the compatibility of different materials towards the solvents required in the production of OLED 1. When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 3 Compatibility of equipment materials towards solvents used for the production of OLED 1

Compatibility list of plastics/elastomers towards typical solvent and reagents

0	no data
1	resistant
2	partially resistant
3	conditionally resistant
4	not resistant

PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
PVDF	Polyvinylidene fluoride				

Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Anisole	1	0	0	0	0	0	4	4	1	0	4	4	4	4	4	4	2	0
Ethanol	1	1	1	2	1	1	2	3	1	1	1	1	2	3	1	3	1	1
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 4 shows the production equipment and the components that are not made of steel or glass and the type of materials including the number of those pieces. The equipment is as follows: pendulum centrifuge, three sizes of reactors, a large filter, 3 stirrable tank pallets, equipment for sampling, vacuum drying oven, compressed air diaphragm pump, dry vacuum compressor, vacuum line. Each equipment contains numerous “small components”.

These components are essential parts of the equipment, are/maybe re-used for some time and batches, cleaned in between, and disposed of after a certain time of usage. The time of usage depends on the components: whereas a filter is only used once; o-rings/seals are replaced when damaged; also, valves are used for a long time. When we speak of “components” in the following all of above-mentioned variants are meant.

The number of components relevant for production of OLED 1 is immense. Ca 1100 pieces require materials made of fluoropolymers whereas about 20 pieces are made of other materials.

Table 4 Production equipment and materials used for the production of OLED 1

Equipment	Component/Element		Material	Number
100 L pendulum centrifuge, gummed	filter cloth	material	PE-fiber	1
	ball valve	lining	PFA	2
		seal	PTFE	4
	lid	seal	PTFE	1
	bearing housing	material	PTFE	1
	pump, submersion, pipe	material	PTFE	17
2500 L reactor, VA-steel	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PFTE	1
		seals	PTFE	200
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seal	PTFE/Viton	2
	tube	camlock coupling	PTFE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
1600 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		discharge tube	PTFE	1
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	300

Equipment	Component/Element		Material	Number
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seal	PTFE/Viton	2
	tube	camlock coupling	PTFE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
2500 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seal	PTFE	300
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PTFE	6
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
125 L single-layer filter	seals	material	PFTE	10
	sterile screw connection	material	FEP/Silikon	4
	ball valve	lining	PFA	4
		seal	PTFE	8
	material	filter plate	Cellulose-Kieselguhr	1
800 L heated, stirrable tank pallet	seals	connection	PTFE	4
	ball valve	lining	PFA	2
		seal	PTFE	4
500 L heated, stirrable tank pallet	seals	connection	PTFE	4
	ball valve	lining	PFA	2
		seal	PTFE	4
800 L heated, stirrable tank pallet	seals	connection	PTFE	4
	ball valve	lining	PFA	2
		seal	PTFE	4
sampling	vials	lid + seal	PP/PTFE	4
vacuum drying oven	seals	door	FEP/Silikon	1
		O-rings	PTFE/Silikon	20
	hordes	foils	PTFE	6
compressed air diaphragm pump	tube	camlock coupling	PTFE	4
	seals	material	PTFE	2
	membrane	material	PFTE	2
SIHI dry vacuum compressor	seals	condenser	PTFE	5

Equipment	Component/Element		Material	Number
		body	FEP/Viton	1
	butterfly valve	lining	PFA/PTFE	2
	valve	gas- and liquid rinsing	PTFE	2
vacuum line	seals	material	PTFE	50

2.1.2. Production of OLED 2: Presentation of compatible materials for the production equipment and implementation in the production

Based on the solvents required, the materials in the production equipment have to be chosen. Table 5 shows the compatibility of different materials towards the solvents required in the production of OLED 2.

When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 5 Compatibility of equipment materials towards solvents used for the production of OLED 2

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Ethanol	1	1	1	2	1	1	2	3	1	1	1	1	2	3	1	3	1	1
Ethyl acetate	1	1	1	2	3	3	4	4	1	1	3	0	4	4	4	4	3	3
n-Heptane	1	1	1	1	1	1	1	1	1	1	4	4	1	1	4	4	4	4
Toluene	1	0	1	2	1	1	3	3	1	0	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 6 shows the production equipment and the components that are not made of steel or glass and the type of materials including the number of those pieces. The equipment is as follows: pendulum centrifuge, peeler centrifuge, three sizes of reactors, a large filter, equipment for sampling, vacuum drying oven, compressed air diaphragm pump, dry vacuum compressor, vacuum line. Each of these equipment contains numerous “small components”.

The number of components is immense: ca 1100 pieces require materials made of fluoropolymers whereas about 20 pieces can be made of other materials.

Table 6 Production equipment and materials used for the production of OLED 2

Equipment	Component/Element		Material	Number
100 L pendulum centrifuge, gummed	filter cloth	material	PE-fiber	1
	ball valve	lining	PFA	1
		seal	PTFE	2
	lid	seal	PTFE	1
	bearing housing	material	PTFE	1
	pump, submersion, pipe	material	PTFE	17
40 L peeler centrifuge	tri-clamp	material	PTFE/Viton	4
	seals	door	FEP/Silikon	2
		O-rings	FEP/Silikon	15
	pump, submersion, pipe	material	PTFE	17
630 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	300
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PTFE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
100 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	200
	entry system	bag	PE	5

Equipment	Component/Element		Material	Number
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PTFE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
1600 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		discharge tube	PTFE	1
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	300
	entry system	bag	PE	5
		seals	PTFE/Viton	2
		butterfly valve	PTFE	1
	tube	camlock coupling	PTFE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
125 L single-layer filter	seals	material	PFTE	10
	sterile screw connection	material	FEP/Silikon	4
	ball valve	lining	PFA	4
		seal	PTFE	8
	material	filter plate	Cellulose-Kieselguhr	1
vacuum drying oven	seals	door	FEP/Silikon	1
		O-rings	PTFE/Silikon	20
	hordes	foils	PTFE	6
sampling	vials	lid + seal	PP/PTFE	4
compressed air diaphragm pump	tube	camlock coupling	PTFE	4
	seals	material	PFTE	2
	membrane	material	PFTE	2
SIHI dry vacuum compressor	seals	condenser	PFTE	5
		body	FEP/Viton	1
	butterfly valve	lining	PFA/PTFE	2
	valves	gas- and liquid rinsing	PFTE	2
vacuum line	seals	material	PTFE	50

2.1.3. Production of OLED 3: Presentation of compatible materials for the production equipment and implementation in the production

Based on the solvents required, the materials in the production equipment have to be chosen. Table 7 shows the compatibility of different materials towards the solvents required in the production of OLED 3.

When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 7 Compatibility of equipment materials towards solvents used for the production of OLED 3

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
2-Propanole	1	1	1	2	1	1	1	1	1	1	1	1	3	3	1	1	1	1
Anisole	1	0	0	0	0	0	4	4	1	0	4	4	4	4	4	4	2	0
2-Methyl-2-butanole	1	1	1	2	1	0	1	4	1	1	3	3	1	1	0	0	1	3
Sodium hydroxide solut	1	1	1	1	3	3	3	4	1	1	1	0	3	3	4	4	1	1
Tetrahydrofurane	1	0	4	4	3	3	4	4	1	1	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 8 shows the production equipment and the components that are not made of steel or glass and the type of materials including the number of those pieces. The equipment is as follows: two sizes of reactors, two large filters, equipment for sampling, packaging material, compressed air diaphragm pump, dry vacuum compressor, vacuum line. Each of these equipment contains numerous "small components".

The number of components is immense: ca 600 pieces require materials made of fluoropolymers whereas about 10 pieces are made of other materials.

Table 8 Production equipment and materials used for the production of OLED 3

Equipment	Component/Element		Material
100 L reactor, glass-lined	vessel	lid	FEP/Silikon
		seals	PFTE
	ball valve	lining	PFA
		seal	PFTE
	bottom valve	seat + seal	PFTE
	glass construction	Protego	PFTE
		seals	PFTE
	entry system	bag	PE
		butterfly valve	PFTE
		seals	PFTE/Viton
	tube	camlock coupling	PFTE
	filter	tri-clamp	PFTE/Viton
		body gasket	FEP/Silikon
		candle	PFTE
160 L reactor, glass-lined	vessel	lid	FEP/Silikon
		seals	PFTE
	ball valve	lining	PFA
		seal	PFTE
	bottom valve	seat + seal	PFTE
	glass construction	Protego	PFTE
		seals	PFTE
	entry system	bag	PE
		butterfly valve	PFTE
		seals	PFTE/Viton
	tube	camlock coupling	PFTE
	filter	tri-clamp	PFTE/Viton
		body gasket	FEP/Silikon
		candle	PFTE
125 L single-layer filter	seals	material	PFTE
	sterile screw connection	material	FEP/Silikon
	ball valve	lining	PFA
		seal	PFTE

Equipment	Component/Element		Material
	material	material plate + cloth	Cellulose-Kieselguhr + PE-fiber
35 L single-layer filter	seals	material	PFTE
	sterile screw connection	material	FEP/Silikon
	ball valve	lining	PFA
		seal	PTFE
	material	material plate + cloth	Cellulose-Kieselguhr + PE-fiber
packaging material	container	seal	FEP/Silikon
sampling	vials	lid + seal	PP/PTFE
compressed air diaphragm pump	tube	camlock coupling	PTFE
	seals	material	PTFE
	membrane	material	PFTE
SIHI dry vacuum compressor	seals	condenser	PTFE
		body	FEP/Viton
	butterfly valve	lining	PFA/PTFE
	valves	gas- and liquid rinsing	PTFE
vacuum line	seals	material	PTFE

![Merck logo]

2.1.4. Production of intermediate for API: Presentation of compatible materials for the production equipment and implementation in the production

Based on the solvents required, the materials in the production equipment have to be chosen. Table 9 shows the compatibility of different materials towards the solvents required in the production of an intermediate for API.

When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 9 Compatibility of equipment materials towards solvents used for the production of intermediate for API

Compatibility list of plastics/elastomers towards typical solvent and reagents

●	0	no data
●	1	resistant
●	2	partially resistant
●	3	conditionally resistant
●	4	not resistant

PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
PVDF	Polyvinylidene fluoride				

Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Acetone	1	1	1	2	3	4	4	4	1	1	1	0	4	4	3	3	2	2
Dichloro methane	1	1	2	4	1	3	3	3	1	1	4	4	4	4	4	4	4	4
Methanol	1	1	1	1	1	1	3	4	1	1	1	0	3	3	2	2	1	1
Sodium hydroxide solut	1	1	1	1	3	3	3	4	1	1	1	0	3	3	4	4	1	1
Tetrahydrofurane	1	0	4	4	3	3	4	4	1	1	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 10 shows the production equipment and the components that are not made of steel or glass and the type of materials including the number of those pieces. The equipment is as follows: two sizes of reactors, a large filter, vacuum drying oven, scrubber, equipment for sampling, compressed air diaphragm pump, dry vacuum compressor, vacuum line. Each of these equipment contains numerous "small components".

The number of components is immense. Ca 600 pieces require materials made of fluoropolymers whereas about 20 pieces are made of other materials.

Table 10 Production equipment and materials used for the production of an intermediate for API

Equipment	Component/Element		Material	Number
630 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	200
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PTFE	8
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
400 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PTFE	10
	bottom valve	seat + seal	PTFE	2
	glass construction	Protego	PTFE	1
		seals	PTFE	200
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PTFE	6
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
125 L single-layer filter	seals	material	PFTE	10
	sterile screw connection	material	FEP/Silikon	4
	ball valve	lining	PFA	4
		seal	PTFE	8
	material	material plate + cloth	Cellulose-Kieselguhr + PE-fiber	1
vacuum drying oven	seals	door	FEP/Silikon	1

Equipment	Component/Element		Material	Number
		O-rings	PTFE/Silikon	10
	hordes	foils	PTFE	6
	heating system + vacuum system	tube	PTFE	10
	tri-clamp	material	PTFE/Viton	4
	container	seal	FEP/Silikon	2
scrubber	seals	material	EPDM	15
	pump	material	PTFE	2
P002, ADA-107 ML400L auf DN200 ETFE	seals	material		4
P002, ADA-110 ML630L auf DN200 Hast	seals	material		4
sampling	vials	lid + seal	PP/PTFE	4
compressed air diaphragm pump	tube	camlock coupling	PTFE	4
	membrane	material	PFTE	2
	seals	material	PTFE	2
SIHI dry vacuum compressor	seals	condenser	PTFE	5
		body	FEP/Viton	1
	butterfly valve	lining	PFA/PTFE	2
	valve	gas- and liquid rinsing	PTFE	2
vacuum line	seals	material	PTFE	50

2.1.5. Purification of a polymer for patterning process in semiconductor manufacturing: Presentation of compatible materials for the production/processing equipment and implementation in the production/processing

Based on the solvents required, the materials in the production/processing equipment have to be chosen. Table 11 shows the compatibility of different materials towards the solvents required in the processing of polymer purification.

When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 11 Compatibility of equipment materials towards solvents used for the purification of a polymer for patterning process in semiconductor manufacturing

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
2-Propanole	1	1	1	2	1	1	1	1	1	1	1	1	3	3	1	1	1	1
Acetonitrile	1	1	1	1	1	1	3	4	1	1	3	0	4	4	0	0	0	0
Cyclohexane	1	1	1	2	1	1	1	1	1	1	4	4	1	0	4	4	4	4
Ethyl acetate	1	1	1	2	3	3	4	4	1	1	3	0	4	4	4	4	3	3
t-Butyl methyl ether	1	1	2	2	1	0	4	4	0	0	4	4	4	4	0	0	0	0
PGMEA	1	0	0	0	0	0	4	4	1	0	1	0	4	4	0	0	0	0
Tetrahydrofurane	1	0	4	4	3	3	4	4	1	1	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 12 shows the production equipment and the components that are not made of steel or glass and the type of materials including the number of those pieces. The equipment is as follows: three different reactors, three agitated pressure filters, three vacuum drying ovens, equipment for sampling, compressed air diaphragm pump, dry vacuum compressor, vacuum line. Each of these equipment contains numerous "small components".

The number of components/elements that can be classified as consumables is immense: ca 1200 pieces require materials made of fluoropolymers whereas about 30 pieces are made of other materials.

Table 12 Production equipment and materials used for the purification of a polymer for patterning process in semiconductor manufacturing

Equipment	Component/Element		Material	Number
100 L reactor, glass	vessel	lid	FEP/Silikon	2
		seal	PFTE	4
	ball valve	lining	PFA	2
		seal	PFTE	4
	bottom valve	seat + seal	PFTE	2
	glass construction	Protego	PFTE	1
		seals	PFTE	450
	entry system	bag	PE	5
		butterfly valve	PFTE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PFTE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
100 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PFTE	10
	bottom valve	seat + seal	PFTE	2
	glass construction	Protego	PFTE	1
		seals	PFTE	200
	entry system	bag	PE	5
		butterfly valve	PFTE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PFTE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
160 L reactor, glass-lined	vessel	lid	FEP/Silikon	2
		seals	PFTE	4
	ball valve	lining	PFA	5
		seal	PFTE	10
	bottom valve	seat + seal	PFTE	2
	glass construction	Protego	PFTE	1

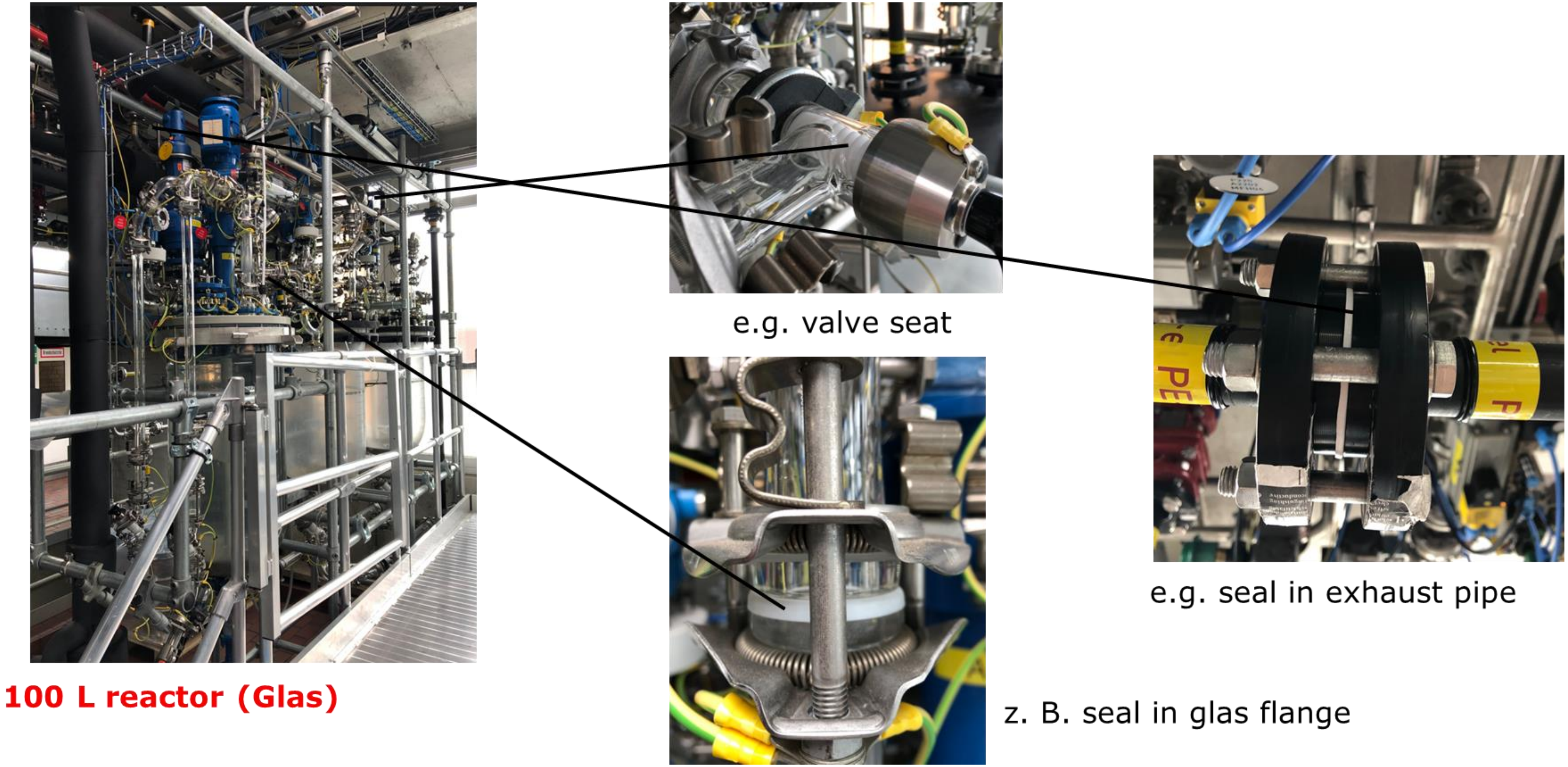
Equipment	Component/Element		Material	Number
		seals	PTFE	200
	entry system	bag	PE	5
		butterfly valve	PTFE	1
		seals	PTFE/Viton	2
	tube	camlock coupling	PFTE	4
	filter	tri-clamp	PTFE/Viton	2
		body gasket	FEP/Silikon	6
		candle	PFTE	1
agitated pressure filter	filter support fabric	material	ETFE	1
	filter layer 1	material	ECTFE	1
	filter layer 2	material	PTFE	1
	seals	material	PTFE	20
	stirrer	coating	Polyetheretherketon (PEEK)	1
	stopcock	material	PTFE	5
agitated pressure filter	filter support fabric	material	ETFE	1
	filter layer 1	material	ECTFE	1
	filter layer 2	material	PTFE	1
	seals	material	PTFE	20
	stirrer	lining	Polyetheretherketon (PEEK)	1
	stopcock	material	PTFE	5
agitated pressure filter	filter support fabric	material	ETFE	1
	filter layer 1	material	ECTFE	1
	filter layer 2	material	PTFE	1
	seals	material	PTFE	20
	stirrer	coating	Polyetheretherketon (PEEK)	1
	stopcock	material	PTFE	5
vacuum drying oven	seals	door	PTFE/Silikon	1
		O-rings	PTFE/Silikon	20
	hordes	foils	PTFE	6
	ball valve	lining	PTFE	3
	glass construction	seals	PTFE	40
	shovel	material	PE/PS/PP	1
	container	seal	FEP/Silikon	2
vacuum drying oven	seals	door	PTFE/Silikon	1
		O-rings	PTFE/Silikon	20
	hordes	foils	PTFE	6
	ball valve	lining	PTFE	3
	glass construction	seals	PTFE	40
	shovel	material	PE/PS/PP	1
	container	seal	FEP/Silikon	2
vacuum drying oven	seals	door	PTFE/Silikon	1
		O-rings	PTFE/Silikon	20

Equipment	Component/Element		Material	Number
	hordes	foils	PTFE	6
	ball valve	lining	PTFE	3
	glass construction	seals	PTFE	40
	shovel	material	PE/PS/PP	1
	container	seal	FEP/Silikon	2
sampling	vials	material		9
compressed air diaphragm pump	tube	camlock coupling	PTFE	10
	seals	material	PTFE	2
	membrane	material	PFTE	4
SIHI dry vacuum compressor	seals	condenser	PTFE	5
		body	FEP/Viton	1
	butterfly valve	lining	PFA/PTFE	2
	valves	gas- and liquid rinsing	PTFE	2
vacuum line	seals	material	PTFE	50

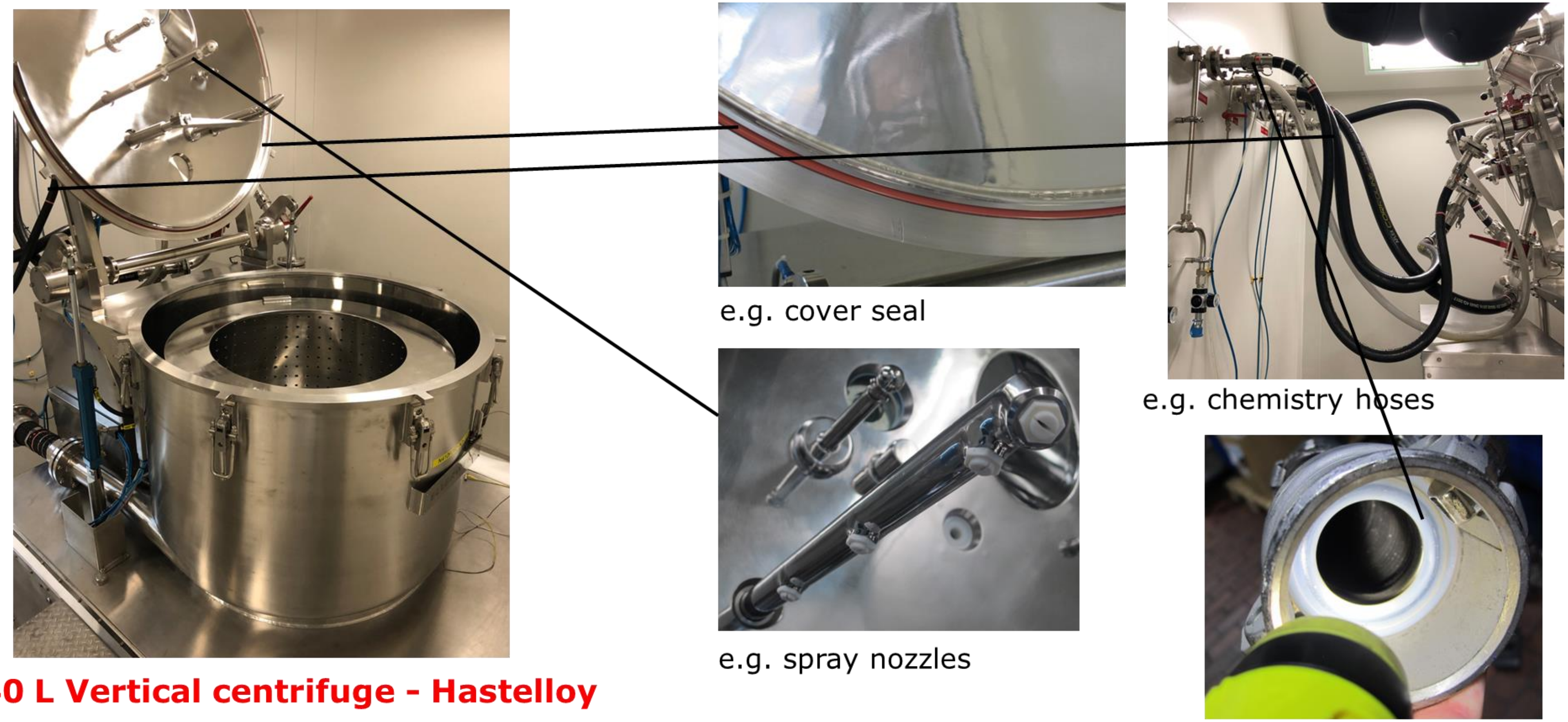
2.1.6. Typical examples of equipment with PFAS components in plant 1

On the following pages some exemplary pictures are shown taken from different equipment and components in plant 1. This visualizes the variety of uses and applications of fluoropolymers in a chemical plant. Of course, this is only a very small part of the large number of components mentioned in the tables above.

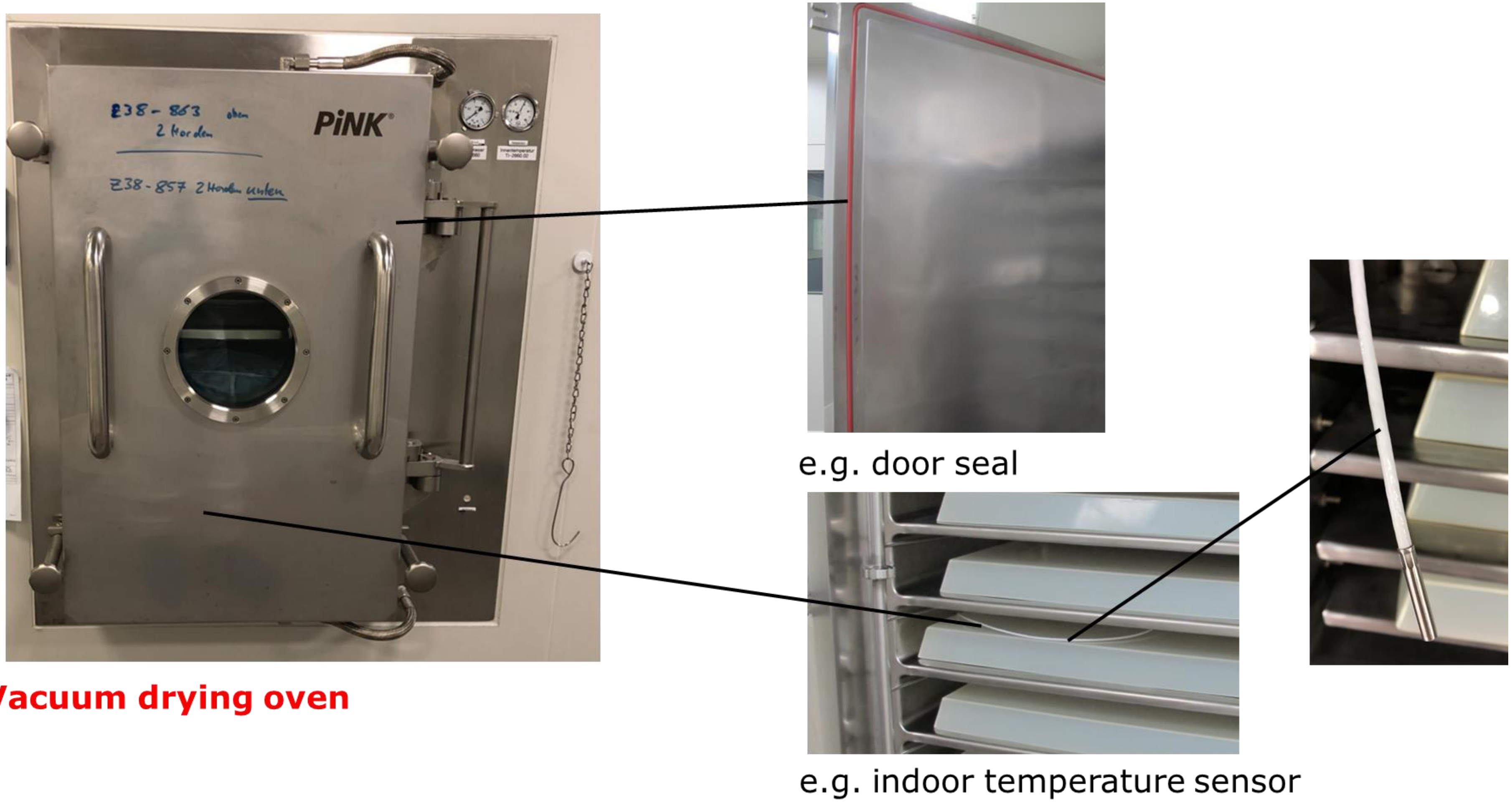
Picture 1 Typical equipment with PFAS components – 100 L reactor



Picture 2 Typical equipment with PFAS components - centrifuge



Picture 3 Typical equipment with PFAS components – vacuum drying oven



Picture 4 Typical equipment with PFAS components – 1000L reactor

Reactor (1000 L)

e.g. Ball valve

2.2. Solvents required for the manufacturing/processing in plant 2 and in plant 3

As it can be seen in Table 13, in plant 2 almost exclusively organic solvents are required for the production of the mentioned three products, e.g., ethanol, n-heptane, toluene, sodium hydroxide solution.

Table 13 Solvents used in the production in plant 2

	Acetone	Acetnonitrile	Anisole	1-Butanole	t-Butyl methyl ether (10-50°C)	Cyclohexane	Dichloro methane	Ethanol	Ethyl acetate	n-Heptane (10-60 °C)	Methanol	2-Propanole (20-95 °C)	PGMEA	Sodium hydroxide solution (21-32 %, 50 °C)	Sodium hydrogen carbonate solution (20 °C)	Tetrahydrofurane	Toluene (0-110°C)	Water (20-50 °C)	Water/HCl (30 %; -10 - 50°C)
OLED 4				x				x				x		x			x	x	
Liquid crystal								x		x							x		
Intermediate for liquid crystal										x							x		

As it can be seen in Table 14, in plant 3 almost exclusively organic solvents are required for the production/processing steps of the four mentioned products, e.g., ethanol, toluene, 2-propanole.

Table 14 Solvents used in the production/processing in plant 3

	Acetone	Acetnonitrile	Anisole	1-Butanole	t-Butyl methyl ether (10-50°C)	Cyclohexane	Dichloro methane	Ethanol	Ethyl acetate	n-Heptane (10-60 °C)	Methanol	2-Propanole (20-95 °C)	PGMEA	Sodium hydroxide solution (21-32 %, 50 °C)	Sodium hydrogen carbonate solution (20 °C)	Tetrahydrofurane	Toluene (0-110°C)	Water (20-50 °C)	Water/HCl (30 %; -10 – 50°C)
Excipient for vaccine												x			x		x	x	
Purification of excipient 1																			
Purification of excipient 2																			x
Cosmetic raw material					x			x						x					

2.2.1. Presentation of compatible materials for the production equipment in plant 2 and plant 3

Based on the solvents required, the materials in the production equipment have to be chosen. Table 15 to Table 21 show the compatibility of different materials towards the solvents required in the production/processing of products in the plants 2 and 3 in the respective selected week.

When looking on the green circles in the table below, it is evident that a use of PTFE/FEP/PFA or FKM is required.

Table 15 Compatibility of equipment materials towards solvents used for the production of OLED 4

Compatibility list of plastics/elastomers towards typical solvent and reagents

0	no data
1	resistant
2	partially resistant
3	conditionally resistant
4	not resistant

PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
PVDF	Polyvinylidene fluoride				

Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
2-Propanole	1	1	1	2	1	1	1	1	1	1	1	1	3	3	1	1	1	1
Ethanol	1	1	1	2	1	1	2	3	1	1	1	1	2	3	1	3	1	1
Sodium hydroxide solut	1	1	1	1	3	3	3	4	1	1	1	0	3	3	4	4	1	1
Toluene	1	0	1	2	1	1	3	3	1	0	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 16 Compatibility of equipment materials towards solvents used for the production of Liquid Crystal

Compatibility list of plastics/elastomers towards typical solvent and reagents

0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant						

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant						

Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Ethanol	1	1	1	2	1	1	2	3	1	1	1	1	2	3	1	3	1	1
n-Heptane	1	1	1	1	1	1	1	1	1	1	4	4	1	1	4	4	4	4
Toluene	1	0	1	2	1	1	3	3	1	0	4	4	4	4	4	4	4	4

Table 17 Compatibility of equipment materials towards solvents used for the production of an intermediate for liquid crystal

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant						

Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
n-Heptane	1	1	1	1	1	1	1	1	1	1	4	4	1	1	4	4	4	4
Toluene	1	0	1	2	1	1	3	3	1	0	4	4	4	4	4	4	4	4

Table 18 Compatibility of equipment materials towards solvents used for the production/processing of Excipient for vaccine

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
2-Propanole	1	1	1	2	1	1	1	1	1	1	1	1	3	3	1	1	1	1
Toluene	1	0	1	2	1	1	3	3	1	0	4	4	4	4	4	4	4	4
Water	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1

Table 19 Compatibility of equipment materials towards solvents used for the processing of Purification of excipient 1

No solvent required during processing of this material

Table 20 Compatibility of equipment materials towards solvents used for the processing of Purification of excipient 2

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Hydrochloric acid (35 %)	1	1	1	1	1	1	1	2	1	1	3	0	4	4	3	4	1	2

Table 21 Compatibility of equipment materials towards solvents used for the production/processing of Cosmetic raw material

Compatibility list of plastics/elastomers towards typical solvent and reagents

		PTFE	Polytetrafluorethylene	FKM	Fluorocarbon-based Fluoroelastomer Materials	EPDM	Ethylene Propylene Diene (Monomer) Rubber
0	no data	FEP	Fluorinated ethylene propylene	FFKM	Perfluorelastomers	NBR	Nitrile Butadiene Rubber
1	resistant	PFA	Perfluoroalkoxyl polymer			VMQ	Vinyl Methyl Silicone
2	partially resistant	ECTFE	ethylene chloro trifluoro ethylene			CSM	Chlorosulfonated polyethylene synthetic rubber
3	conditionally resistant	PVDF	Polyvinylidene fluoride				
4	not resistant			**Compatibility list based on own testing, DECHEMA Werkstoffliste, and information from material supplier**			

	Fluorine containing material										Fluorine free material							
	PTFE/FEP/PFA		ECTFE (Halar)		PVDF		FKM ("Viton")		FFKM ("Kalrez")		EPDM		NBR		VMQ ("Silikon")		CSM ("Hypalon")	
Solvent	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C	20°C	50°C
	Spalte2	Spalte3	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2	Auswahl2
Ethanol	1	1	1	2	1	1	2	3	1	1	1	1	2	3	1	3	1	1
t-Butyl methyl ether	1	1	2	2	1	0	4	4	0	0	4	4	4	4	0	0	0	0
Sodium hydroxide solut	1	1	1	1	3	3	3	4	1	1	1	0	3	3	4	4	1	1

2.2.2. Typical examples of equipment with PFAS components in plant 2

On the following pages three examples are displayed for larger equipment. In the tables the components with fluoropolymers are shown, in the pictures some selected (!) indications are given where fluoropolymers are used in the equipment.

The high number of fluoropolymers is visible in

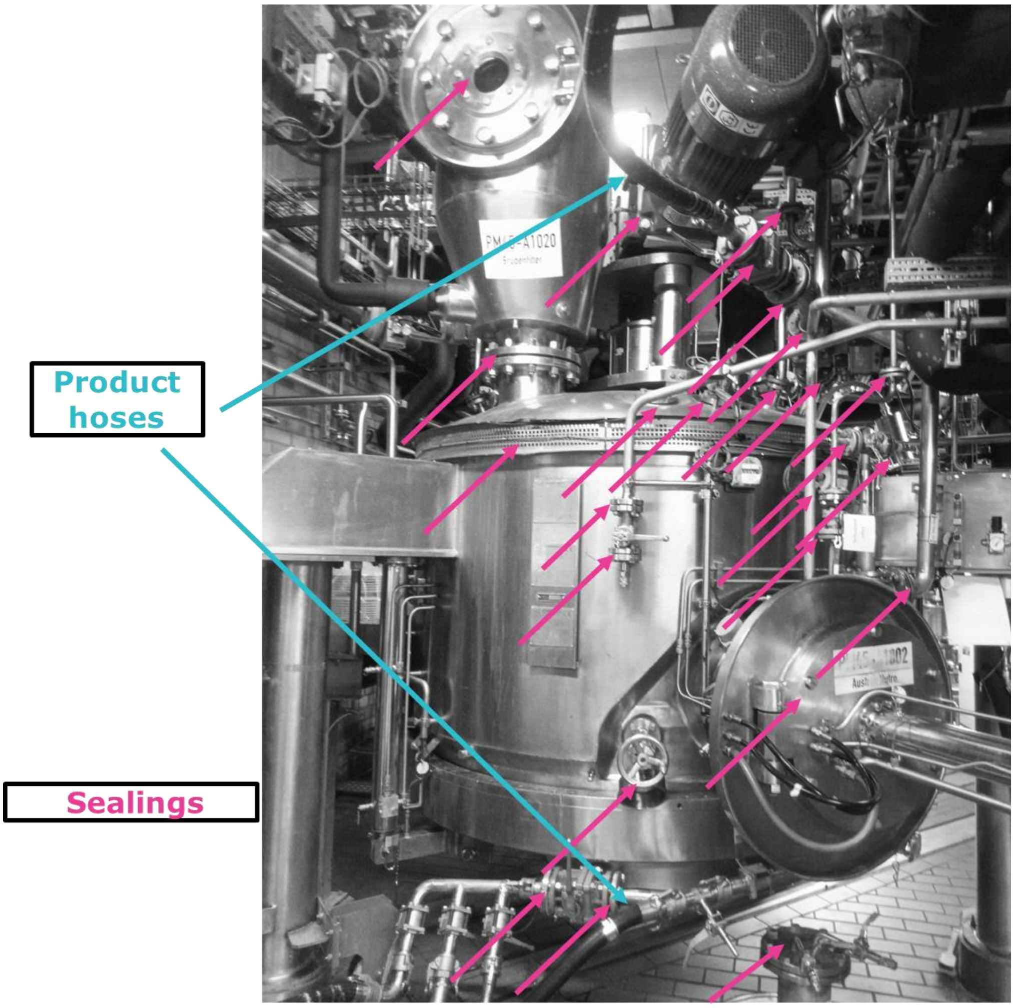
Picture 5 to Picture 7 of the equipment, indicated with arrows.

Example 1: agitated nutsche filter

Table 22 Overview of components with fluoropolymers (highlighted in pink) in an agitated nutsche filter

Plant parts
Agitated nutsche filter
Stirring unit
Hydraulic system
Vapour filter
Nitrogen buffer container
Container
Centrifugal pump
Container
Container
Propeller stirrer
Candle filter
Heat exchanger
Candle filter
Vacuum pump
Pump
Expansion vessel
Container
Centrifugal pump
Centrifugal pump
Tubing system
Tubing system

Picture 5 Agitated nutsche filter with selected indications of fluoropolymers

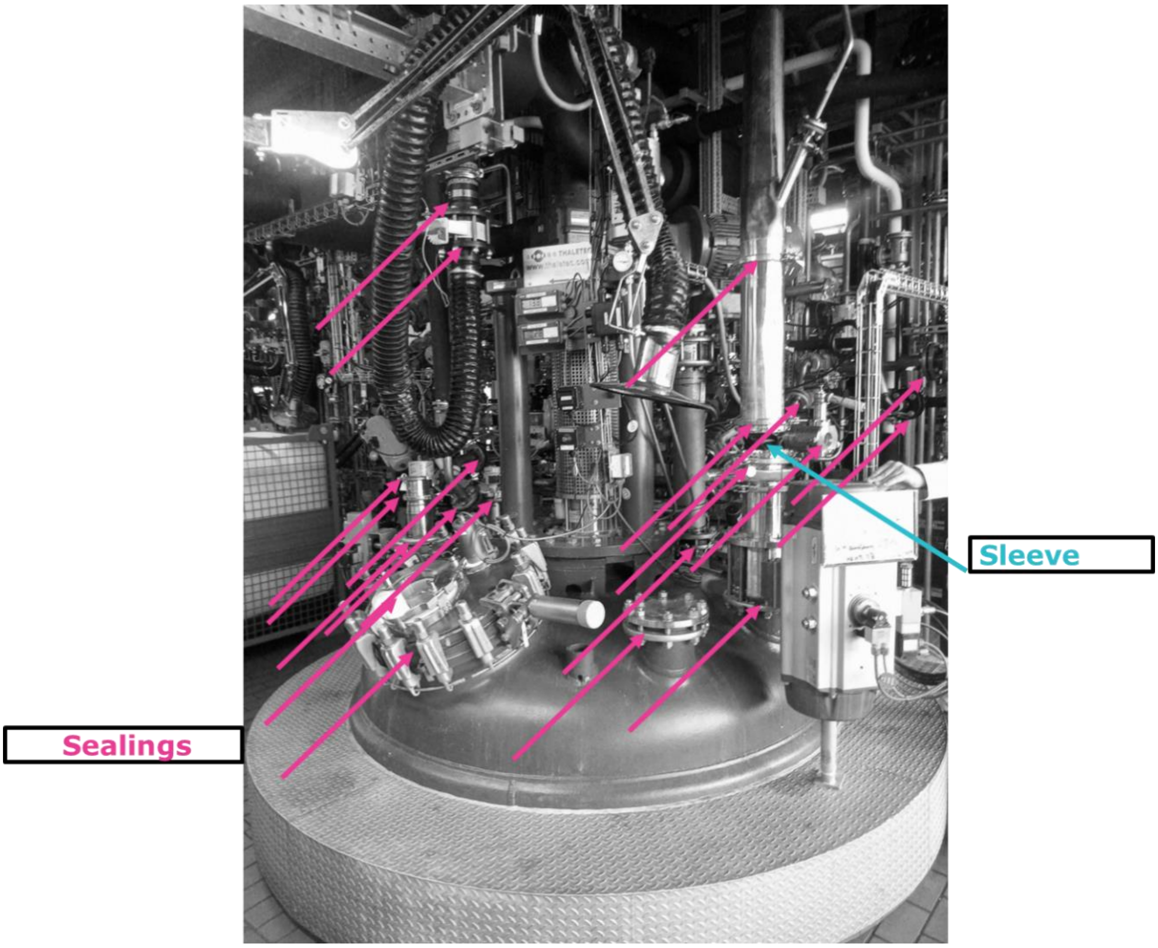


Example 2: reactor

Table 23 Overview of components with fluoropolymers (highlighted in pink) in a reactor

Plant parts
Reactor vessel
Baffles
Stirring unit
Container
Pump (mobile)
Container
Container (mobile)
Scale
Pump (mobile)
Container (mobile)
Container (mobile)
Scale
Pump (mobile)
Filter
Tank
Heat exchanger
Pump
Pump

Picture 6 reactor with selected indications of fluoropolymers

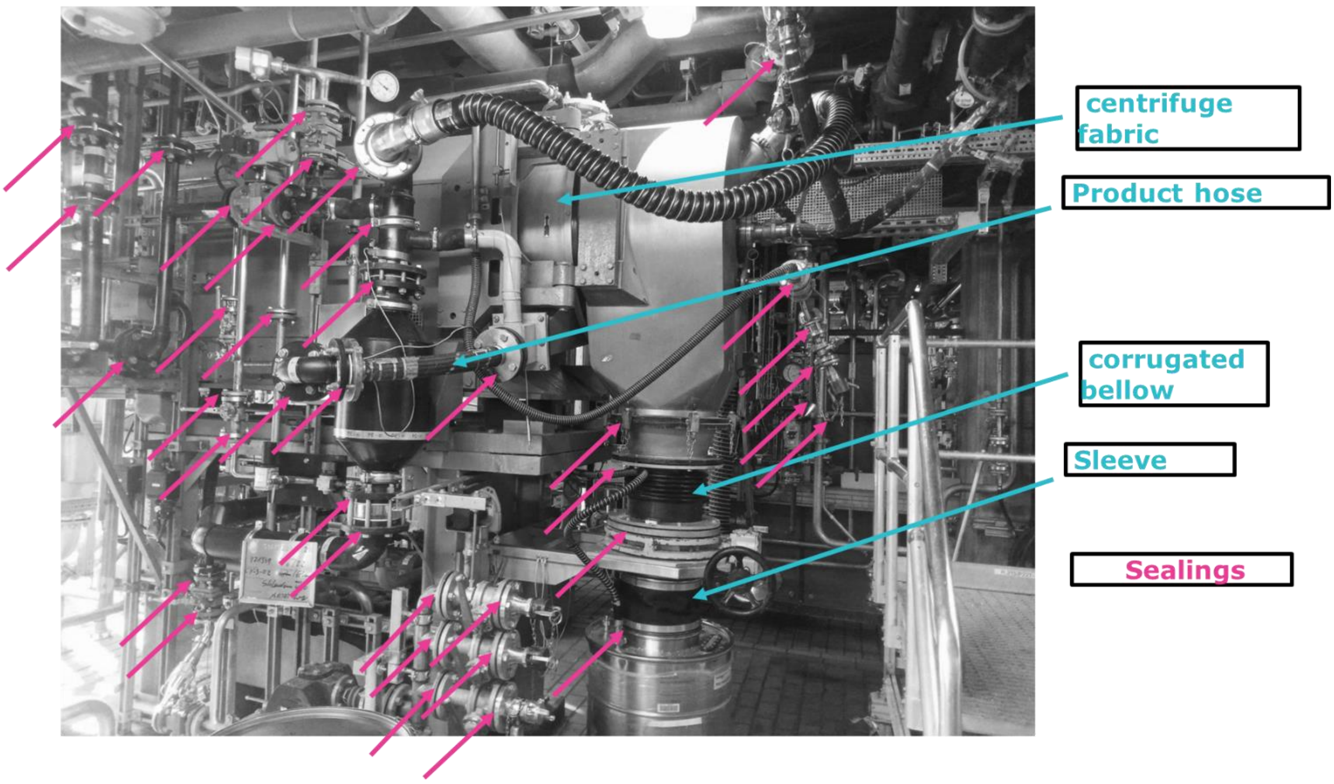


Example 3: centrifuge

Table 24 Overview of components with fluoropolymers (highlighted in pink) in centrifuge

Plant parts
Centrifuge basket
Candle filter
Container
Container
Centrifugal pump
Container
Nitrogen reducing station
Heat exchanger
Air Operated Diaphragm Pump
Nitrogen line
Tubing system

Picture 7 centrifuge with selected indications of fluoropolymers

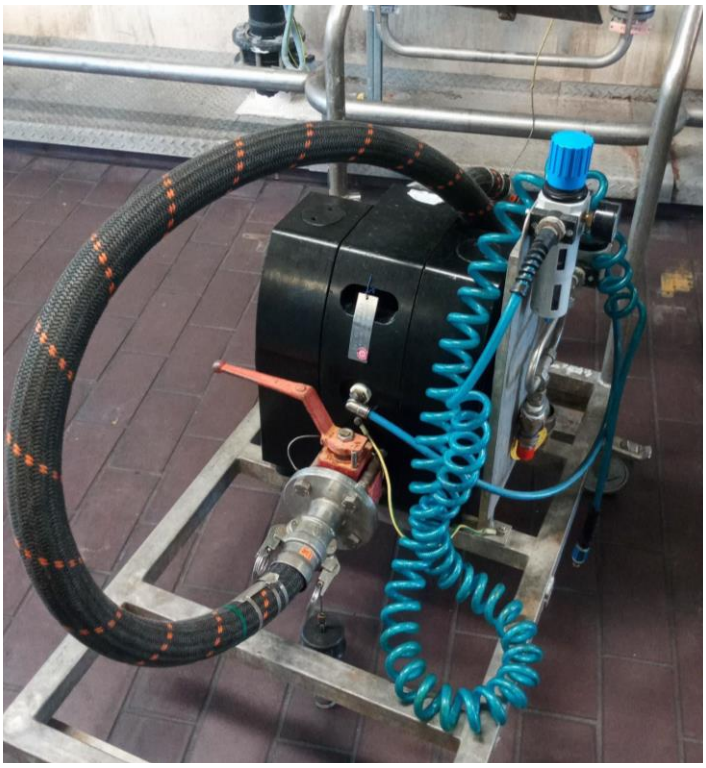


2.2.3. Further examples of fluoropolymer equipment/components

Below some further examples of fluoropolymer-equipment/-components are shown. This type of equipment/components is used when required by the solvents/reaction solution:

*Picture 8 **Product distributor** with PTFE lined hoses and several sealings*

Picture 9 ***Mobile pump*** *with body, hose, and sealings made of PTFE*



Picture 10 Further fluoropolymer-(containing) components

Corrugated bellow made of PTFE

Manometer with PTFE liner

Filter cartridge made of fluoropolymer

Inflatable gasket for filling unit

Ball valve with PTFE sealing

Gasket made of PTFE

Pump with PTFE inliner

All flexible hoses are made of PTFE or have PTFE inliner

O-rings in different sizes, all coated with FEP

2.3. Summary and conclusion on the use of fluoropolymer-components in production equipment

Representative examples for production processes show that the required solvents are mainly organic solvents. Based on the compatibility information obtained from material suppliers and experiments conducted in our testing lab, the use of fluoropolymers is indispensable to run the equipment and processes in line with occupational health & safety requirements and environmental requirements. For consequences of the use of fluorine-free components, please refer to chapter 2.4.

For each production process, a large number of equipment is used. In each equipment, a huge number of fluoropolymer parts are installed: ~600-1200 fluoropolymer materials in total in equipment for the exemplary production processes. The number of fluorine-free components is very low and in the range 10-20 (where, e.g., contact to solvent is excluded). The manifold use of the fluoropolymers is evident from the tables and pictures.

In addition to the manufacturing plants, fluoropolymers are also required in the packaging of some chemicals for a safe transportation.

2.4. Investigation of alternatives and (in)compatibilities

There are at least the following requirements on the materials used in the production equipment:

- Chemical resistance towards solvents (and towards the mixture of chemicals in a reaction process, including organic solvents of different types a well as strong acids and bases)
- No leaching of component material into product
- Chemical durability
- Temperature stability

For our multipurpose plants with changing chemical conditions from production process to production process, the chemical resistance (to protect worker and the environment) and the linked stability towards leaching (to protect the product) are the main reasons for the use of fluoropolymer in our equipment.

The use of fluoropolymers enables us to run a multipurpose plant with flexible production processes for different kind of products and solvents and to continuously comply with the obligations to minimize any exposures of chemicals towards the worker and the environment, as e.g., laid down in the Chemical Agents Directive (98/24/EC) and, e.g., the German Gefahrstoffverordnung (GefVO, §7 (4)).

It should be noted that the costs of fluoropolymer exceed the costs of fluorine-free components by far: as an example, the costs for a (simple) O-ring (ca 10.1 cm x 0.5 cm) are shown as used to tighten lines and hoses:

Material of O-ring	Ca costs for O-ring [Euro/piece]
NBR	0.60
Silicon	1.50
EPDM	2.30
FKM*	4.30
Silicon mantled with FEP*	17
PTFE*	19
FFKM*	230

* PFAS

Fluoropolymers are chemically resistant and do not leach. They do not change their form, durability, behavior during the use, e.g., in contact with solvents. Data for the resistance of fluoropolymers are shown below.

Our company has a testing lab and experience which material can be used in which components of a production plant. This is usually checked by multiple tests.

(In)Compatibility data with fluorine-free components

Respective information from external sources is complemented by tests in our laboratory regarding the (in)compatibility of fluorine-free towards common solvents.

In the following plenty of evidence is provided concerning the incompatibility of the fluorine-free polymers EPDM (Ethylene Propylene Diene (Monomer) Rubber), Silicon, NBR (Nitrile Butadiene Rubber). These materials were exposed to dichloro methane, heptane, tetrahydrofurane, or toluene, respectively, for 4 days at 40°C. These solvents are commonly used in chemical production as it can be seen in Table 2, Table 13, and Table 14.

The size, mass and volume of the components are measured before exposure, after 4 days of exposure and after drying. Pictures of the components are taken at the same time. Pictures of the "exposure vessel with component including solvent" are taken at start, after 24 h, at the end of the exposure (96 h).

The results of the measurements are shown in Table 25. Pictures of the components and component with solvent exposure are displayed in

Picture 11 to Picture 27. Please note that the pictures shown are not necessarily in the same scale. Therefore, the scale paper in the background should be used as reference.

The exposure of solvent at 40°C for 4 days results for all material-solvent combinations to a distinct increase in volume (except for NBR in heptane). The relative volume increase ranges from about 50 % to > 200 %.

For EPDM in heptane a curving of the component is observed (Picture 12), whereas a rupture of the component was noted for EPDM in THF (Picture 13), and EPDM in toluene (Picture 14).

Furthermore, there is a mass change of the component after exposure to solvent with subsequent drying. This mass change is in the range of 2-5 % and similar for all components; for the flat seal made of EPDM and the NBR components, a discoloration was observed (yellowish), whereas for the EPDM round seal and for the silicon component, the solvents remain transparent. The discoloration of the solvents and, even more, the (relative) mass change are indicators for leaching of "polymer ingredients" into the product. This contamination of the product is not acceptable for our fine chemical industry customers, e.g., coming from pharmaceutical industry, semiconductor industry or display industry.

Compatibility data with the fluoropolymer PTFE

In our test lab, a test was performed to check the compatibility of a black and a white PTFE sealing for IBCs; samples of these components were stored in closed bottles with dichloro methane, ethylacetate, xylene and tetrahydrofurane (THF) for 40 days at 80°C. These conditions are extreme when comparing to the conditions used for the exemplary experiment with the fluorine-free components. Before and after exposure, the sizes of the samples were measured, and the weight was determined. A second measurement of the weight of the samples was done after drying for 12 hours at 80°C. GC-FID analyses of the solvents after the exposure were conducted and compared with chromatograms of blank solvents without PTFE exposure.

A volume change was not observed for the PTFE-components. The relative mass change is shown in Table 26. A very slight increase of mass of the samples was observed with all solvents: directly after exposure the increase was in the range 0.1-1.1 %; after 12 h drying at 80°C, the relative mass change was lower and in the range 0-0.7 %. A discoloration of solvent during exposure was not observed (see Picture 28). A chromatogram of the dichloro methane used for exposure to white PTFE showed only some small additional peaks (Picture 30) compared to blank dichloro methane (Picture 29). A chromatogram with dichloro methane used for exposure of black PTFE (Picture 31) was almost identical to the blank and less peaks were found than with white PTFE. The amount of leaching components was estimated to be very low and in the ppm-range.

Table 25 Overview on compatibility experiments conducted with 4 fluorine-free components in 4 different solvents including information on relative volume change, relative mass change and color change of solvent

Sample declaration material	Material	Sample declaration Solvent	Solvent	temperature °C	Calculation of rel. volume change according to DIN ISO 1817 using density balance rel. volume change in % after 4d in solvent	after ~72h drying	rel. mass change in % after 4d in solvent	after ~72h drying	Colour of solvent after 24h in solvent	after 96h in solvent
A	EPDM (flat seal)	1	DCM	40	58.74	-8.19	36.86	-4.38	distinctly yellow	distinctly yellow
A	EPDM (flat seal)	2	heptane	40	91.54	-9.19	30.93	-4.27	slightly yellow	bright yellow
A	EPDM (flat seal)	3	THF	40	99.72	-6.71	43.11	-4.49	distinctly yellow	distinctly yellow
A	EPDM (flat seal)	4	toluene	40	126.56	-7.85	51.09	-4.76	bright yellow	distinctly yellow
B	EPDM (round seal)	1	DCM	40	72.21	-3.15	88.53	-2.61	no discoloration	no discoloration
B	EPDM (round seal)	2	heptane	40	132.11	-3.76	86.33	-3.1	no discoloration	no discoloration
B	EPDM (round seal)	3	THF	40	125.11	-3.89	102.76	-3.21	no discoloration	no discoloration
B	EPDM (round seal)	4	toluene	40	116.77	-3.51	105.4	-2.91	no discoloration	no discoloration
C	Silicon	1	DCM	40	89,00	-3.52	78.52	-2.23	no discoloration	no discoloration
C	Silicon	2	heptane	40	111.24	-3.5	52,00	-2.21	no discoloration	no discoloration
C	Silicon	3	THF	40	117.02	-0.81	71.04	0.63	no discoloration	no discoloration
C	Silicon	4	toluene	40	100.43	-6.79	59.11	-5.39	no discoloration	no discoloration
D	NBR	1	DCM	40	217.73	-4.76	234.62	-3.91	slightly yellow	bright yellow
D	NBR	2	heptane	40	2.54	-3.81	2.92	-3.44	no discoloration	slightly yellow
D	NBR	3	THF	40	187.22	-5.1	140.72	-4.5	slightly yellow	bright yellow
D	NBR	4	toluene	40	135.01	-5.04	98.56	-4.34	slightly yellow	bright yellow

For use of elastomers, a relative volume change of		means		
0-10%		resistant	EPDM	Ethylene Propylene Diene (Monomer) Rubber
10-20%		partially resistant	NBR	Nitrile Butadiene Rubber
20-30%		conditionally resistant		
>30%	or <-2%	not resistant		

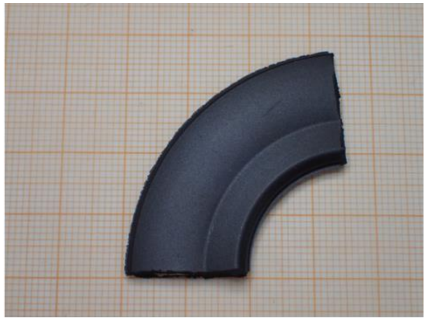
Table 26 Relative mass change of two PTFE samples after 40 days of exposure to different solvents and subsequent drying

Material	**Relative mass change [%] ***			
	Dichloro methane	**Ethylacetate**	**Tetrahydrofurane**	**Xylene**
PTFE white	0.5/0.2	0.2/0.1	0.1/.01	0.1/0
PTFE black	1.1/0.7	0.4/0.2	0.5/0.3	0.5/0.3

* first figure represents the change directly after removal of sample from solvent; the second figure was obtained after 12 h drying at 80°C

Picture 11 Experiment with EPDM component and dichloro methane: before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

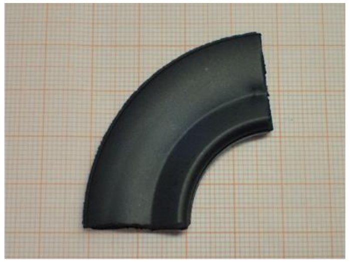
EPDM (gr) in dichloro methane (DCM) –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 20mm

↑↓ ~ 37mm



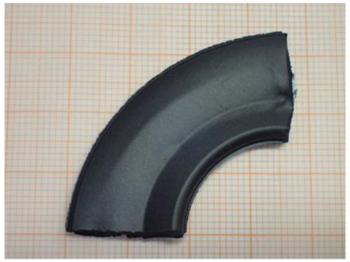
after ~96h DCM

↔ ~ 22mm

↑↓ ~ 43mm

Rel. volume change: 59%

Rel. mass change: 37%



after drying

↔ ~ 20mm

↑↓ ~ 34mm

Rel. volume change: -8%

Rel. mass change: -4%

EPDM (gr) in DCM –
Start (000) – n24h (001) – n96h (004)

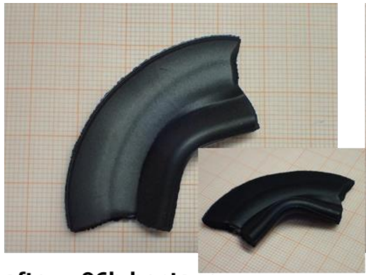
Picture 12 Experiment with EPDM component and heptane: before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

EPDM (gr) in heptane –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 20mm

↑↓ ~ 37mm



after ~96h heptane

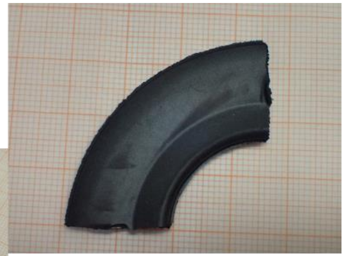
↔ ~ 20mm *curved (!)*

↑↓ ~ 42mm curved *(!)*

Rel. volume change: 92%

Rel. mass change: 31%

- curved



after drying

↔ ~ 20mm

↑↓ ~ 35mm

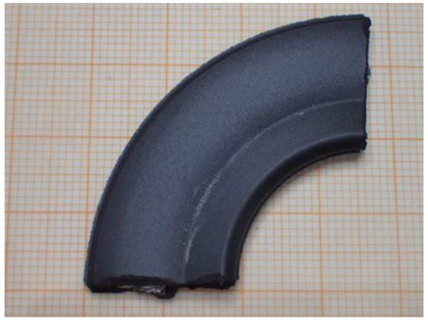
Rel. volume change: -9%

Rel. mass change: -4%

EPDM (gr) in heptane –
Start (000) – n24h (001) – n96h (004)

Picture 13 Experiment with EPDM component and tetrahydrofurane (THF): before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

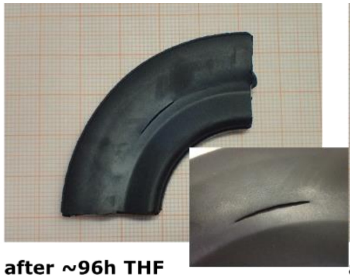
EPDM (gr) in tetrahydrofurane (THF) –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 20mm

↑↓ ~ 37mm



after ~96h THF

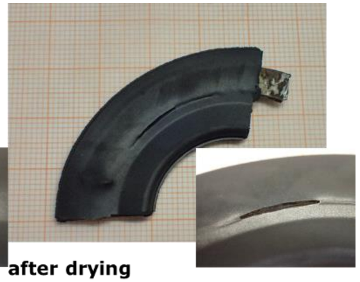
↔ ~ 25mm

↑↓ ~ 45mm

Rel. volume change: 99%

Rel. mass change: 43%

- ripped



after drying

↔ ~ 18mm

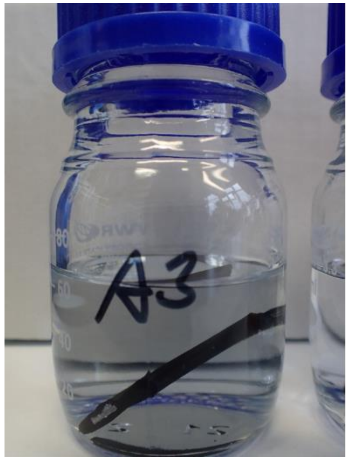
↑↓ ~ 34mm

Rel. volume change: -7%

Rel. mass change: -4,5%

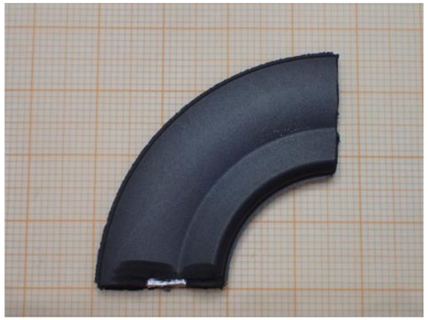
- ripped

EPDM (gr) in THF –
Start (000) – n24h (001) – n96h (004)



Picture 14 Experiment with EPDM component and toluene before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

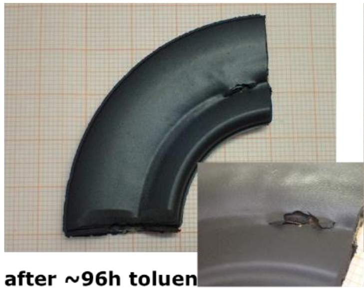
EPDM (gr) in toluene –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 20mm

↑↓ ~ 37mm



after ~96h toluen

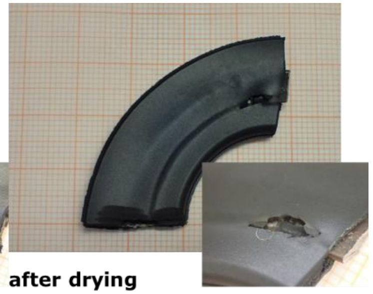
↔ ~ 25mm

↑↓ ~ 48mm

Rel. volume change: 127%

Rel. mass change: 51%

- ripped



after drying

↔ ~ 20mm

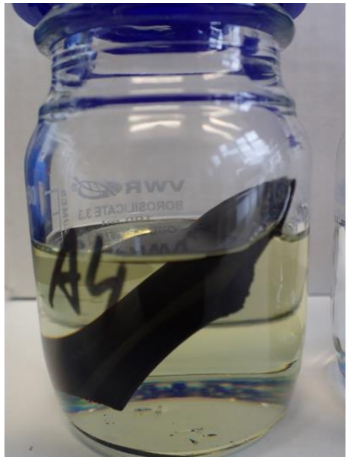
↑↓ ~ 34mm

Rel. volume change: -8%

Rel. mass change: -5%

- ripped

EPDM (gr) in toluene –
Start (000) – n24h (001) – n96h (004)



Picture 15 Experiment with EPDM component and dichloro methane (DCM) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

EPDM (kl) in DCM –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 28mm

Cord thickness ~ 3.5mm

after ~96h DCM

↔ ~ 34mm

Cord thickness ~ 4.5mm

Rel. volume change: 72%

Rel. mass change: 88.5%

after drying

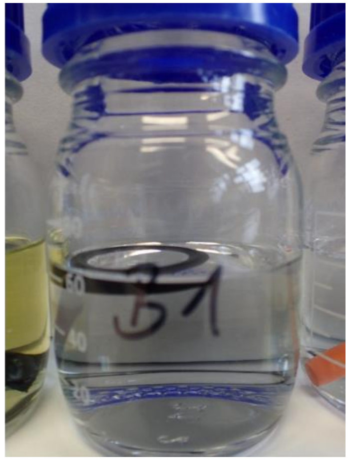
↔ ~ 20mm

Cord thickness ~ 3mm

Rel. volume change: -3%

Rel. mass change: -2.5%

EPDM (kl) in DCM–
Start (000) – n24h (001) – n96h (004)



Picture 16 Experiment with EPDM component and heptane before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

EPDM (kl) in heptane –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 28mm

Cord thickness ~ 3.5mm

after ~96h heptane

↔ ~ 35/37mm

Cord thickness ~ 5mm

Rel. volume change: 132%

Rel. mass change: 86%

after drying

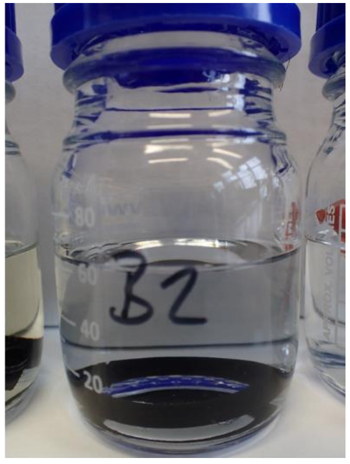
↔ ~ 27mm

Cord thickness ~ 3.5mm

Rel. volume change: -4%

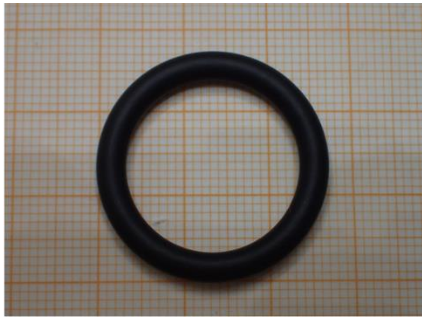
Rel. mass change: -3%

EPDM (kl) in heptane–
Start (000) – n24h (001) – n96h (004)



Picture 17 Experiment with EPDM component and tetrahydrofurane (THF) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

EPDM (kl) in THF –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 28mm

Cord thickness ~ 3.5mm

after ~96h THF

↔ ~ 35/37mm

Cord thickness ~ 5mm

Rel. volume change: 125%

Rel. mass change: 103%

after drying

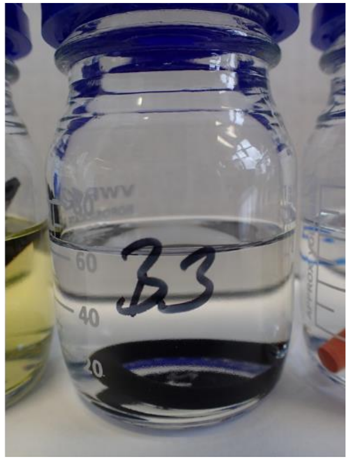
↔ ~ 28mm

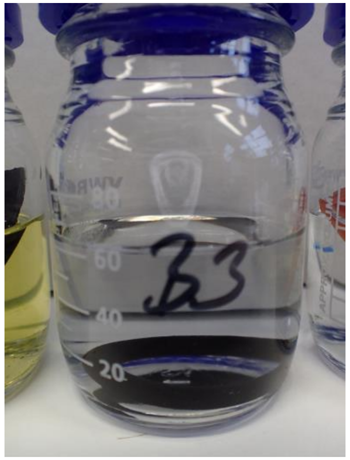
Cord thickness ~ 4mm

Rel. volume change: -4%

Rel. mass change: -3%

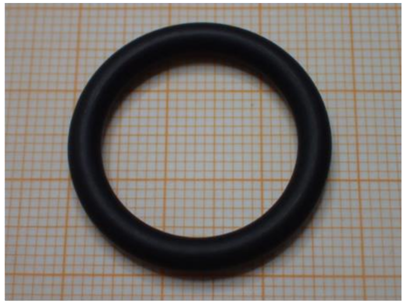
EPDM (kl) in THF–
Start (000) – n24h (001) – n96h (004)





Picture 18 Experiment with EPDM component and toluene before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

EPDM (kl) in toluene –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 28mm

Cord thickness ~ 3.5mm

after ~96h toluene

↔ ~ 36mm

Cord thickness ~ 4.5mm

Rel. volume change: 117%

Rel. mass change: 105%

after drying

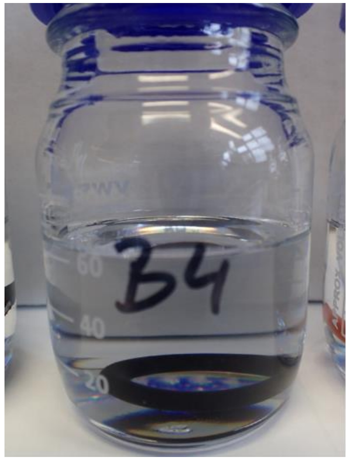
↔ ~ 20mm

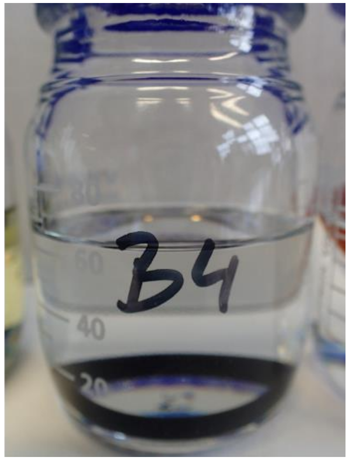
Cord thickness ~ 4mm

Rel. volume change: -3.5%

Rel. mass change: -3%

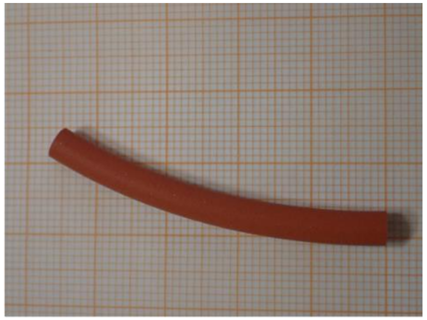
EPDM (kl) in toluene–
Start (000) – n24h (001) – n96h (004)





Picture 19 Experiment with silicon component and dichloro methane (DCM) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

Silicon in DCM –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 47mm

Cord thickness ~ 4.5mm

after ~96h DCM

↔ ~ 57mm

Cord thickness ~ 6mm

Rel. volume change: 89%

Rel. mass change: 79%

after drying

↔ ~ 47mm

Cord thickness ~ 4.5mm

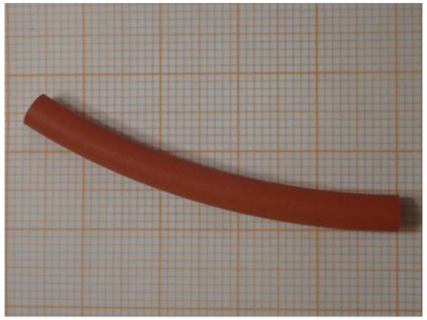
Rel. volume change: -3.5%

Rel. mass change: -2%

Silicon in DCM –
Start (000) – n24h (001) – n96h (004)

Picture 20 Experiment with silicon component and heptane before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

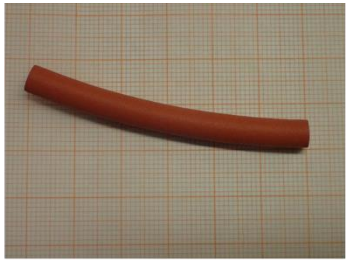
Silicon in heptane –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 48mm

Cord thickness ~ 4.5mm



after ~96h heptane

↔ ~ 61mm

Cord thickness ~ 5mm

Rel. volume change: 111%

Rel. mass change: 52%

after drying

↔ ~ 47mm

Cord thickness ~ 4.5mm

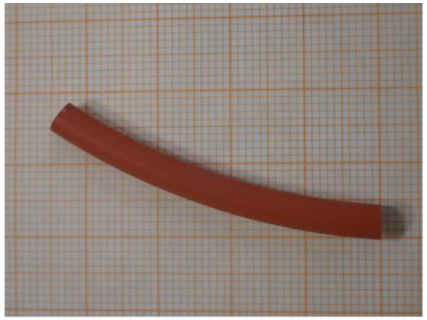
Rel. volume change: -3.5%

Rel. mass change: -2%

Silicon in heptane –
Start (000) – n24h (001) – n96h (004)

Picture 21 Experiment with silicon component and tetrahydrofurane (THF) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

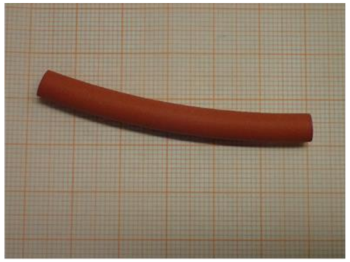
Silicon in THF –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 45mm

Cord thickness ~ 4.5mm



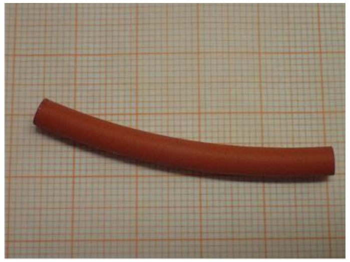
after ~96h THF

↔ ~ 58mm

Cord thickness ~ 6mm

Rel. volume change: 117%

Rel. mass change: 71%



after drying

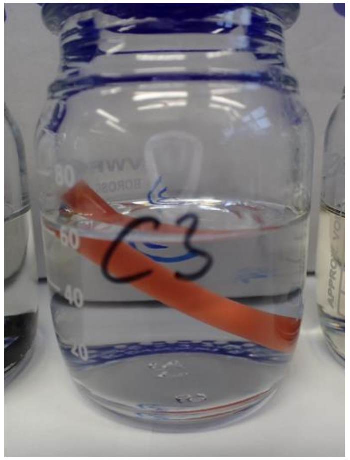
↔ ~ 47mm

Cord thickness ~ 4.5mm

Rel. volume change: -1%

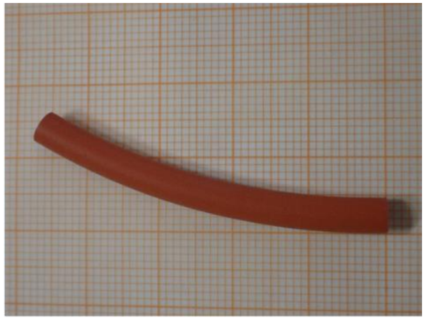
Rel. mass change: 1%

Silicon in THF –
Start (000) – n24h (001) – n96h (004)



Picture 22 Experiment with silicon component and toluene before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

Silicon in toluene –
Start (000) – n96h (004) – after drying (005)



Start

↔ ~ 48mm

Cord thickness ~ 4.5mm

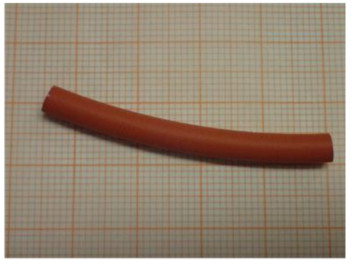
after ~96h toluene

↔ ~ 59mm

Cord thickness ~ 6mm

Rel. volume change: 100%

Rel. mass change: 59%



after drying

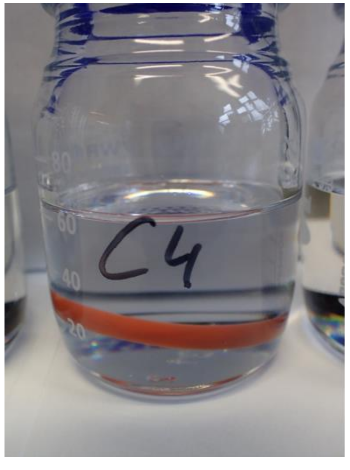
↔ ~ 46mm

Cord thickness ~ 4.5mm

Rel. volume change: -7%

Rel. mass change: -5%

Silicon in toluene –
Start (000) – n24h (001) – n96h (004)



Picture 23 Experiment with NBR component and dichloro methane (DCM) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

NBR in DCM –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 14.5mm

Cord thickness ~ 3mm

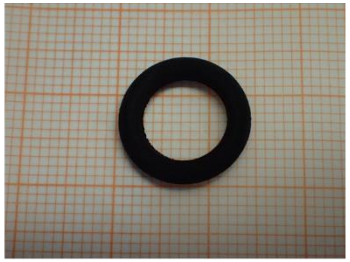
after ~96h DCM

↔ ~ 21.5mm

Cord thickness ~ 4mm

Rel. volume change: 217%

Rel. mass change: 235%



after drying

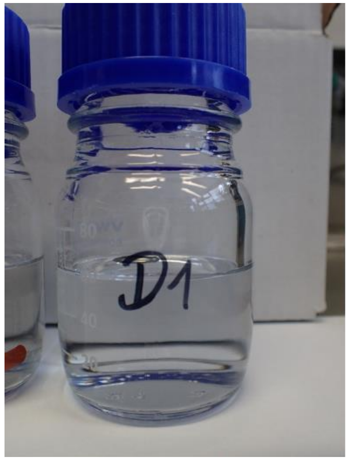
↔ ~ 14.5mm

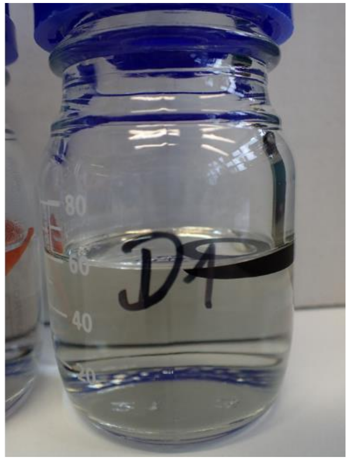
Cord thickness ~ 3mm

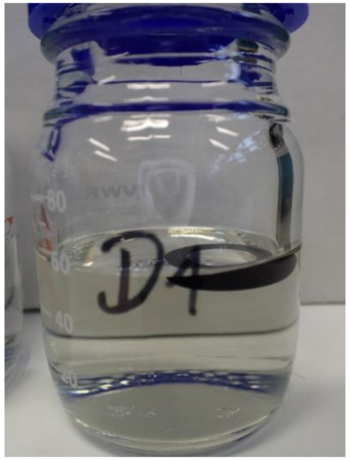
Rel. volume change: -5%

Rel. mass change: -4%

NBR in DCM –
Start (000) – n24h (001) – n96h (004)







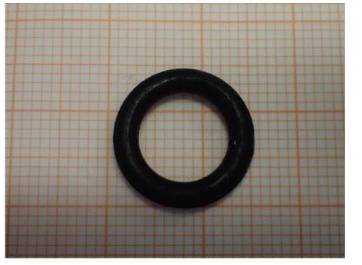
Picture 24 Experiment with NBR component and heptane before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

NBR in heptane –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 14.5mm

Cord thickness ~ 3mm



after ~96h heptane

↔ ~ 15mm

Cord thickness ~ 3.5mm

Rel. volume change: 2.5%

Rel. mass change: 3%

after drying

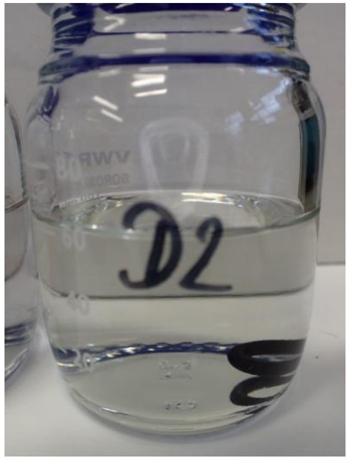
↔ ~ 14.5mm

Cord thickness ~ 3mm

Rel. volume change: -4%

Rel. mass change: -3.5%

NBR in heptane –
Start (000) – n24h (001) – n96h (004)



Picture 25 Coloration of paper towel used for drying of NBR component after 96h exposure to heptane

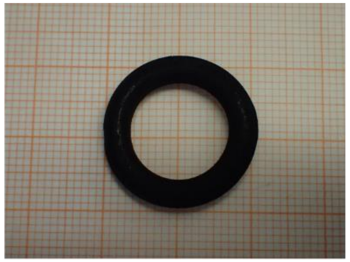
Picture 26 Experiment with NBR component and tetrahydrofurane (THF) before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

NBR in THF –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 14.5mm

Cord thickness ~ 3mm



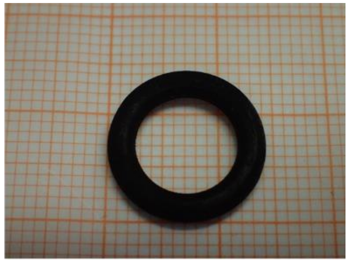
after ~96h THF

↔ ~ 21mm

Cord thickness ~ 4mm

Rel. volume change: 187%

Rel. mass change: 141%



after drying

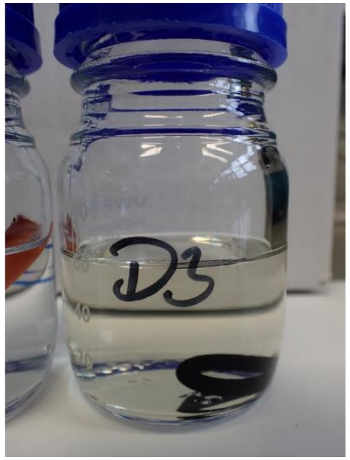
↔ ~ 14mm

Cord thickness ~ 2.5mm

Rel. volume change: -5%

Rel. mass change: -4.5%

NBR in THF –
Start (000) – n24h (001) – n96h (004)



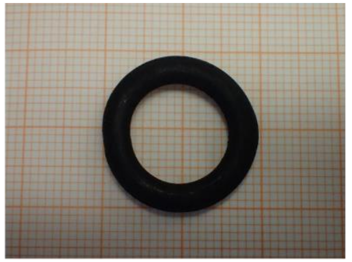
Picture 27 Experiment with NBR component and toluene before start, after 96h of exposure and after drying and within the solvent during the time of the experiment

NBR in toluene –
Start (000) – n96h (004) – after drying (005)

Start

↔ ~ 14.5mm

Cord thickness ~ 3mm



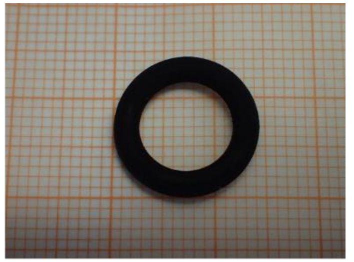
after ~96h toluene

↔ ~ 20mm

Cord thickness ~ 4.5mm

Rel. volume change: 135%

Rel. mass change: 99%



after drying

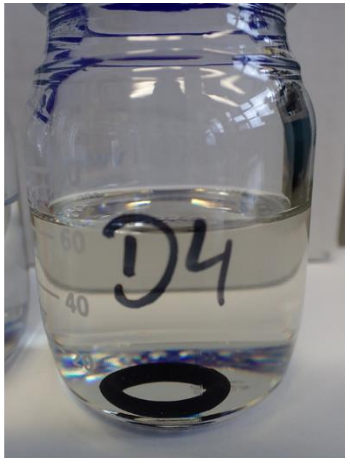
↔ ~ 14.5mm

Cord thickness ~ 3mm

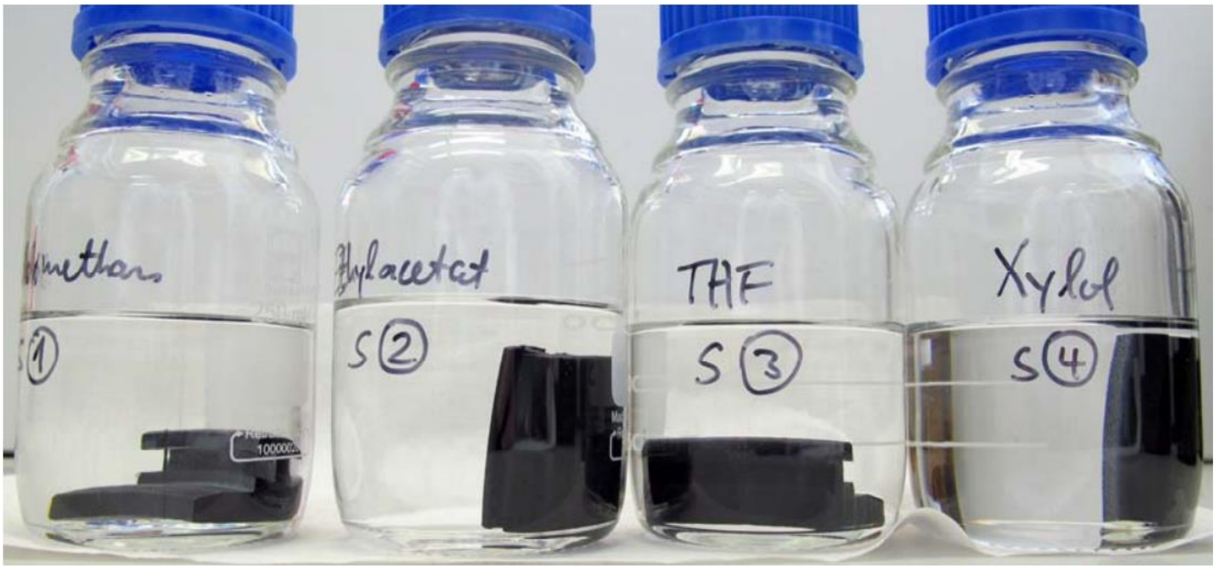
Rel. volume change: -5%

Rel. mass change: -4%

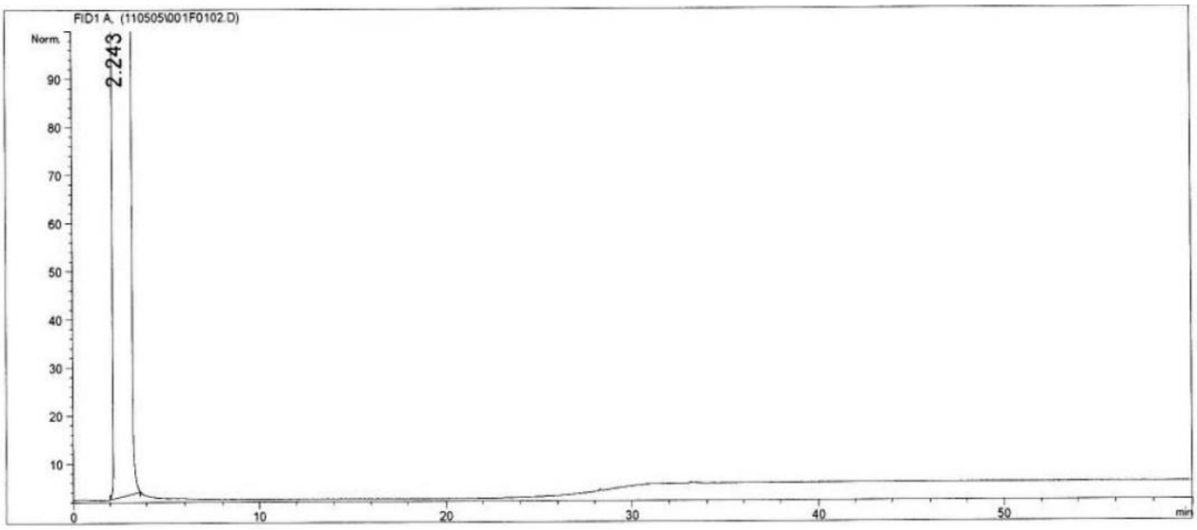
NBR in toluene –
Start (000) – n24h (001) – n96h (004)



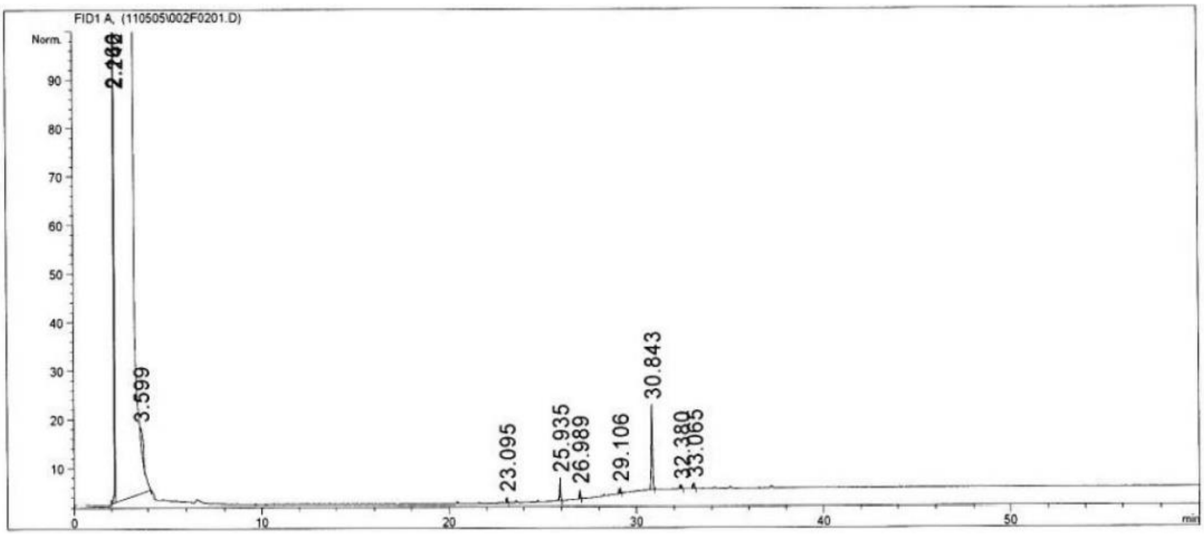
Picture 28 Sample bottle with black PTFE and different solvents after 40 d exposure at 80°C



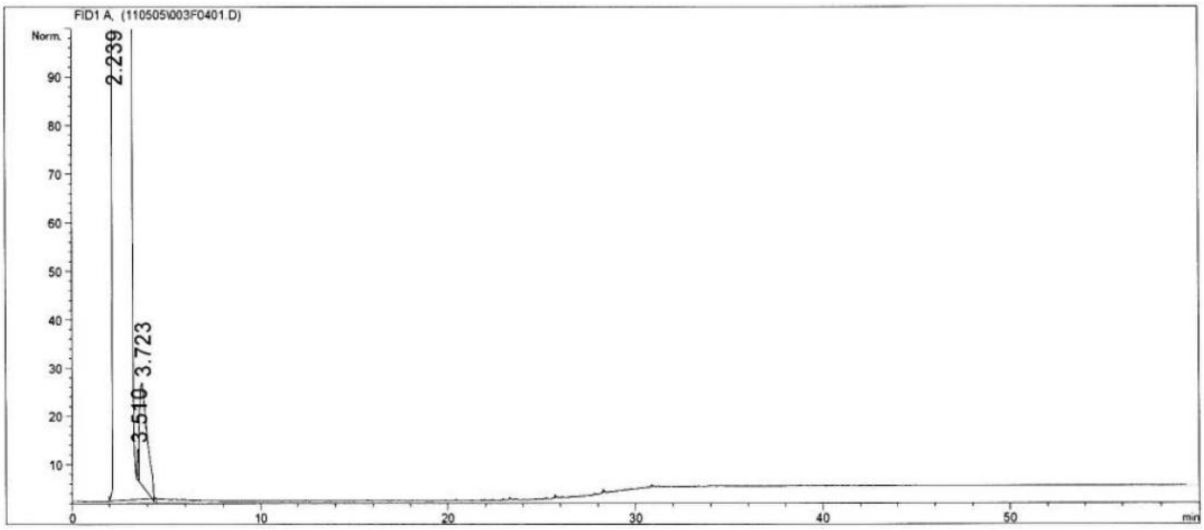
Picture 29 Chromatogram GC-FID, dichloro methane, blank



Picture 30 Chromatogram GC-FID, dichloro methane, after 40 d exposure to PTFE, white



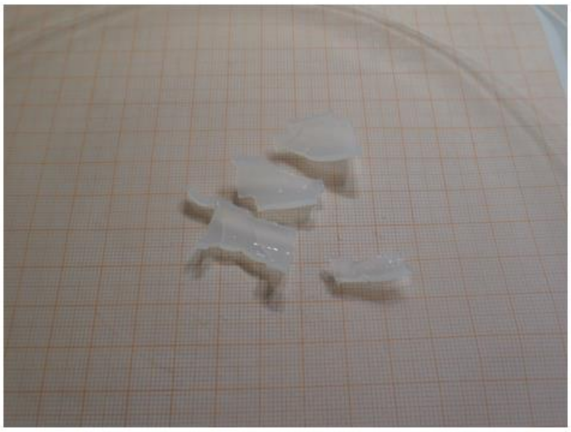
Picture 31 Chromatogram GC-FID, dichloro methane, after 40 d exposure to PTFE, black



Additional data on compatibility testing

The additional example below shows the difficulty and complexity of the compatibility topic: Although silicon is considered as resistant against methanol according to state-of-the-art compatibility tables, a silicon hose was completely deteriorated when exposing to an alkaline solution of methanol at 40°C for 330 h (Picture 32). It should be noted that the solution contained fluorides.

Picture 32 Silicon hose before and after exposure to an alkaline solution of methanol (fluorides containing)



Furthermore, there are additional fluorine-free plastics (e.g., PEEK) and elastomers. Although some of those materials are resistant to (some) organic solvents, all properties of the material have to be considered as well as the explicit area of application: PEEK is a quite hard plastic and could be used for some applications requiring a strong durability (e.g., plastic screws), but PEEK is less suitable for use in flexible sealings, fittings.

Assessment of results of the presented compatibility experiments

The exposure of components made of the fluorine-free materials EPDM, Silicon, and NBR to common organic solvents like dichloro methane, heptane, tetrahydrofurane or toluene resulted in almost all cases in distinct increase in volume; in some cases, a rupture of the component was observed. When these fluorine-free materials are installed into production equipment and exposed to these solvents the increases of volume can lead to leaky connections, fittings, blocked valves…. Leaking production equipment leads to high danger for workers, and the environment and this is contradictory to the minimization rule of the Chemicals Agents Directive and national laws.

In addition, in these experiments a significant mass loss was observed (2-5 % range). This can be interpreted as leaching of “fluorine-free polymer substances” into the solvent (and subsequently potentially the product).

Overall, it can be concluded that the use of these fluorine-free materials is not suitable to fulfill the requirements mentioned at the beginning of this chapter and to fulfill occupational health and safety, environmental, quality and regulatory requirements set to a production facility.

The exposure of components made of PTFE to the common solvents like dichloro methane, ethylacetate, xylene, and tetrahydrofurane under much harsher conditions showed no volume change, a very minor mass increase and a very minor leaching of substances into the solvents (ppm-range).

Overall, it can be concluded that the use of the fluoropolymer PTFE is suitable to fulfill the requirements mentioned at the beginning of this chapter and the occupational health and safety, environmental, quality and regulatory requirements set to a production facility.

When looking into literature and comments from suppliers of such production equipment, there are some statements about the good compatibility of fluorine-free polymers towards the organic solvents. However, as the experiment with the silicon sample with methanol (and fluoride) shows, an in-depth testing and evaluation of a sample of a production equipment is mandatory to ensure safety of workers, the environment, and the product. The use of fluorine-free alternatives is always preferred due to the significant costs of the fluoropolymers, so alternatives are always carefully assessed.

2.5. Conclusion

The use of fluoropolymers in the chemical production is always carefully evaluated due to the high costs for these materials; however, a huge number of different fluoropolymer components is required to run a production that is safe to the worker, the environment and to protect the product. The safety of the production is linked, at least, to the following properties of the materials used:

- Chemical resistance towards solvents (and towards the mixture of chemicals in a reaction process)
- No leaching of component material into product
- Chemical durability
- Temperature stability

Based on the compatibility information obtained from material suppliers and experiments conducted in our testing lab, the use of fluoropolymers is indispensable to run the equipment and processes in line with occupational health & safety requirements and environmental requirements.

No fluorine-free alternative is able to meet these requirements.

Consequently, a (chemical) production with organic solvents is only possible with the use of fluoropolymers; referring to the nature of the C-F bond, an alternative to fluoropolymers cannot be developed.

3. Exposition

Merck Electronics is a downstream user of fluoropolymers. From a life cycle perspective, our use is in the service life stage.

There is no evidence that the use of fluoropolymers in components (such as hoses or PTFE-lined pipelines) leads to significant emissions of PFAS into air or water. Even in case of damage or use of very corrosive substances, emissions of PFAS are considered to be strongly limited.

The amount of fluoropolymers annually disposed of is estimated to be in the range of 30 kg to 100 kg/plant. During inspections, services and maintenance, all parts are checked and replaced, if required.

These figures are considered as very low, especially when comparing to the yearly average use of 1000 t of solvents in plant 1.

Additional information regarding the end of life/waste stage is found in the following chapter.

4. Waste management and recycling

In Merck Electronics an EHS Waste Management Standard provides a consistent framework for waste management across all sites. As waste producer, Merck is responsible for the ultimate disposal of all waste and therefore chooses the service providers with the utmost care, contractually stipulating disposal requirements, especially when it comes to hazardous waste.

The generation of waste is prevented and minimized by, for instance, developing new production processes or optimizing existing ones. Articles are reused and recycled when possible. When prevention or recycling is not feasible, the best is done to recover materials from the waste created. This, of course also applies to production equipment containing PFAS polymers. At the end of life, articles and production equipment containing PFAS polymers, are considered as hazardous waste (contaminated with chemicals), are segregated, and collected, to be treated at a regulated waste disposal facility.

One indispensable pillar of this waste management is the thermal treatment to ensure the proper disposal of our chemical waste. In a hazardous waste incineration plant, waste is treated by high-temperature incineration according to the Federal Immission Control Act and the 17th Ordinance to this Act (17th BImSchV) and the ordinances issued pursuant to it. Requirements for the design of the furnace, the minimum temperatures and specific limit values for emissions of inorganic and organic pollutants are clearly regulated.

According to these ordinances, for hazardous waste incineration plants a minimum incineration temperature of 1,100°C is required for waste with a halogen content in the waste greater than 1%.

As example, information on the hazardous waste incineration plant in Biebesheim, Germany is given here: Two independent incineration lines are used. Each incineration line consists of a rotary kiln with an afterburner chamber and a downstream flue gas cleaning system. The waste is broken down into its atomic and molecular components at a temperature of around 1,200 °C with an open flame. In the downstream post-combustion chamber, the resulting combustion gases are mixed with air to promote optimal burnout. The combustion gases are purified in a multi-stage exhaust gas treatment system (including for example scrubber, fabric filter, activated carbon filter and catalyst, and mercury retention)[i].

Emissions are continuously monitored, and the measurement results transmitted to the competent authorities.

According to Regulation (EU) 2019/1021 and other publications[ii] [iii] [iv] [v] high-temperature incineration is correlated to temperatures > 1,100 °C and 2 seconds contact time. Under these conditions, fluoropolymers are considered to be destroyed (RAC also proposes similar conditions in case of PFAS incineration in the opinion on the PFAS firefighting foam restriction Annex XV dossier [vi]: "If PFAS containing waste is incinerated or co-incinerated, the temperature shall be at least 1 100 °C"). These conditions are achieved in the hazardous waste incinerators used and furthermore the above-described downstream waste gas purification system filters resulting combustion gases in several stages.

As all of the hazardous waste (including fluoropolymers) is disposed of in such incineration plants we conclude that the use of fluoropolymers in our chemical production does not lead to a relevant environmental/human exposure at/after the waste stage.

5. Impact

From the data above, it is evident that a chemical production/processing with organic solvents (and some acids/bases) is only possible with the use of fluoropolymers as only fluoropolymers fulfill the requirements set on a chemical production/processing regarding worker safety, environmental safety and product quality. Due to the unique nature of the C-F bond and the resulting unique properties of the fluoropolymers, it is considered to be impossible to identify adequate alternatives.

Thus, the whole chemical industry in EU would be largely jeopardized with critical impact also on downstream industries as e.g. semiconductor or pharmaceutical industry.

Information on the economic impact on Merck Electronics is given in a **confidential attachment** to the Merck Electronics submission related to PFAS use in chemical manufacturing.

6. Summary and conclusion

Three Merck Electronics plants in Darmstadt, Germany were selected to exemplify the practical importance of PFAS fluoropolymers based on typical productions.

These plants are considered as representative to show current PFAS fluoropolymers use in chemical plants using batch production processes and utilizing a broad set of organic solvents as well as strong acids or bases. In the production processes considered, solvents such as anisole, ethanol, n-heptane, dichloromethane, tetrahydrofuran, and toluene were used.

Final products of the considered examples are for use in the Electronic industry (OLEDs, liquid crystals, process chemicals for semiconductor manufacturing), Pharmaceutical industry (APIs, excipients for vaccine) and Cosmetic industry (cosmetic raw materials).

Due to economic considerations, fluoropolymers are only used in chemical production where absolutely necessary. Accepting the high costs, a huge number of different fluoropolymer components are required to run a production that is safe for the worker, the environment, and ensures product quality. The safety of the production can be directly linked to, at least, the following properties of the materials used:

- Chemical resistance towards solvents (and towards the mixture of chemicals in a reaction process)
- No leaching of component material into product
- Chemical durability
- Temperature stability

Based on the compatibility information obtained from material suppliers and experiments conducted in our testing lab, the use of fluoropolymers is necessary to meet the requirements above and to run the equipment and processes in line with occupational health & safety requirements and environmental requirements.

In addition to manufacturing plants, fluoropolymers are also required in the packaging of some chemicals for safe transportation.

No fluorine-free alternative is able to meet these requirements with the solvents used.

In some literature examples, as well as in some equipment-supplier information, statements can be found about general compatibility of fluorine-free polymers towards some organic solvents. However, practical testing and evaluation of a sample of a production equipment is mandatory to ensure safety of workers, the environment, and the product. Such testing is standard in our operations. Information on potential alternatives given in the set of documents accompanying the published restriction draft is not validated in such a way. Thus, general statements are not necessarily valid for a specific use of these materials.

Fluoropolymer components have turned out to be the only material being able to withstand the various challenging conditions in the manufacturing plants. Due to the unique nature of the C-F bond and the resulting unique properties of the fluoropolymers, it is considered to be impossible to identify adequate alternatives.

Merck Electronics is a downstream user of fluoropolymers. From a life cycle perspective, the use is in the service life stage. The use of fluoropolymers in components (such as hoses or PTFE-lined pipelines) does not lead to significant emissions of PFAS into air or water - even in case of damage or use of very corrosive substances.

The amount of fluoropolymers disposed of annually is estimated to be in the range from 30 to 100 kg per plant.

These figures are considered as very low, especially when compared to the yearly average use of 1000 t of solvents in plant 1.

In the organization of Merck Electronics, an EHS Waste Management Standard provides a consistent framework for waste management across all sites. As a waste producer, Merck is responsible for the ultimate disposal of this waste and therefore chooses the service providers in this regard with the utmost care, contractually stipulating disposal requirements, especially when it comes to hazardous waste.

At the end of life, articles and production equipment containing PFAS polymers are considered contaminated articles, segregated, and collected, to be treated at a hazardous waste incineration plant - conditions under which PFAS are destroyed.

Consequently, we conclude that the use of fluoropolymers in our chemical production does not lead to a significant environmental/human exposure at or after the waste stage.

Chemical production with organic solvents and strong acids/bases is only possible with the use of fluoropolymers as only fluoropolymers fulfill the requirements regarding worker safety, environmental safety, and product quality.

Based on the current broad PFAS restriction proposal, fluoropolymers will not be available anymore for use in chemical production 18 months after entry into force of the restriction.

Thus, the entire chemical industry in the EU would be largely jeopardized by implementation of the current restriction proposal with critical impact also on downstream industries as e.g., semiconductor or pharmaceutical industry.

With the information and facts delivered in the previous chapters, we provided substantial evidence on the indispensable need of fluoropolymers in chemical production plants. There are approximately a thousand fluoropolymer components in a chemical plant to provide the required safety for workers, the environment, and the product. The total amount of fluoropolymers disposed of per year is very low compared with the amount of chemicals used/handled.

No fluorine-free alternative is known to meet the requirements with the solvents used and each and every potential alternative needs adequate, in-depth testing with real production chemicals. Considering the resistance and durability profile needed, suitable alternative substances would likely have comparable persistence properties to PFAS.

With adequate risk management measures related to chemicals as well as to contaminated articles, (including fluoropolymers) exposure to the environment or population during service life and at/after end-of life/waste stage can be strongly limited.

The potential impact of the current restriction proposal on our company is described in the **confidential attachment** to this submission.

We request a thorough adaptation of the restriction proposal reflecting a time-unlimited derogation for the use of fluoropolymers in the chemical industry and the upstream processes to manufacture respective fluoropolymer articles.

[i] HIM- Infos: https://www.indaver.de/entsorgen/anlagen/biebesheim/sonderabfallverbrennungsanlage/

[ii] Yamada, T., Taylor, P. Buck, R. Kaiser, M. Giraud, R. (2005): Thermal Degradation of Fluorotelemer Treated Articles and Related Materials. Chemosphere 61, 974-984.

[iii] UNEP-POPs (2021): UNEP/POPS/COP10/INF20: Guidance on best available techniques and best environmental practices for the use of perfluorooctane sulfonic acid, perfluorooctanoic acid, and their related compounds listed under the Stockholm Convention, p. 29-30, Meeting Documents(brsmeas.org)

[iv] Umweltbundesamt (2020), Texte 137/2022, Sanierungsmanagement für lokale und flächenhafte PFAS Kontaminationen Anhang C: Sanierungsverfahren[iv])) on persistent organic pollutants, thermal treatment processes in particular are suitable for recycling or disposing of waste containing PFAS

[v] UBA; Das Magazin des Umweltbundesamtes, Schwerpunkt; 01, 2020. PFAS -gekommen um zu bleiben

[vi] RAC OPINION ON AN ANNEX XV DOSSIER PROPOSING RESTRICTIONS ON PFAS IN FIREFIGHTING FOAMS (ECHA/RAC/RES-O-0000007226-75-01/F)