Application note | 002633

Environmental

Analysis of PFAS in indoor air using thermal desorption coupled to gas chromatography – mass spectrometry (TD-GC-MS/MS)

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Keywords

Polyfluoroalkyl substances (PFAS), indoor air monitoring, thermal desorption, TD100-xr Advanced, emissions, Micro-Chamber/Thermal Extractor, gas chromatography-mass spectrometry, GC-MS, triple quadrupole, TSQ 9610 mass spectrometer, Advanced Electron Ionization (AEI) source, TRACE 1610 GC

Goal

The aim of this application note is to present a method for the simultaneous analysis of 19 per- and polyfluoroalkyl substances (PFAS) across four different functional groups (perfluoroalkyl carboxylic acids / carboxylates (PFCAs), fluorotelomer alcohols (FTOHs), fluorotelomer carboxylic acids (FTCAs), and perfluorotoctane sulfonamides (FOSAs)) in indoor air using thermal desorption coupled to gas chromatography-mass spectrometry. In addition, the PFAS emission rate from a common consumer product was also evaluated by using a Markes International™ Micro-Chamber/Thermal Extractor™ (µ-CTE™).

Introduction

Per- and polyfluoroalkyl substances (PFAS) consist of one or more alkyl residues where all hydrogen atoms have been replaced by fluorine atoms. These compounds can be found in air as the results of emissions from industrial activities. However, these compounds are also found in indoor air, as they are widely used in consumer products, such as nonstick cookware, water-repellent clothing, stain resistant fabrics and carpets, some cosmetics, and products that resist grease, water, and oil.[1] The presence of PFAS in indoor air can pose risks to human health, in particular for perfluorooctanoic acid (PFOA), as it can bioaccumulate in humans and other air-breathing organisms and has been linked to major health issues such as kidney cancer, testicular cancer, thyroid disease, pregnancy-induced hypertension, and high cholesterol.[2]

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Moreover, some neutral PFAS species (n-PFAS) such as fluorotelomer alcohols (FTOHs), fluorotelomer carboxylic acids (FTCAs), and perfluorooctanesulfonamides (FOSA) can degrade within the body and in the environment to form PFOA.

Thermal desorption (TD) represents a suitable technique for analysis of organic contaminants in air, including ultra-volatile species. Stainless-steel tubes packed with sorbents are used as sampling media to preconcentrate samples from hundreds of liters of air with no requirement for any dilution prior to analysis. This means that single digit pg/m^3 concentrations can be measured when combined with triple quadrupole GC-MS/MS.

In this study, a high-throughput method for the analysis of n-PFAS and PFCAs in indoor air is demonstrated by using thermal desorption coupled to gas chromatography-mass spectrometry.

Experimental

In the experiments described here, a Markes International™ TD100-xr™ Advanced thermal desorber with electronic flow control and equipped with a Markes International™ Internal Standard Addition / Dry Purge (ISDP) accessory for automated addition of gaseous internal standard was used. This sample introduction technique was coupled to a Thermo Scientific™ TRACE™ 1610 Series GC connected to a Thermo Scientific™ TSQ™ 9610 triple quadrupole mass spectrometer, equipped with a Thermo Scientific™ Advanced Electron Ionization (AEI) source. Chromatographic separation was achieved on a Thermo Scientific™ TraceGOLD™ TG-200MS capillary column (30 m × 0.25 mm × 1.0 µm, P/N 26084-2960). The trifluoropropylmethylpolysiloxane stationary phase provides an exceptionally inert phase for improved thermal stability, low column bleed, and reliable run-to-run and batch-to-batch reproducibility.

The Markes International TD100-xr thermal desorption unit offers sequential, unattended analysis of up to 100 samples. Due to the use of electrical cooling for refocusing in the trap, it eliminates both cost and hassle of using a cryogenic fluid. Markes' systems also allow samples to be split and re-collected onto a clean sorbent tube at the tube desorption and/or trap desorption stages, providing "insurance" against failed runs and simplifying demonstration of complete analyte transfer and absence of analytical bias. The re-collection feature allowed the samples to be run twice by using full scan (FS) and timed selected reaction monitoring (t-SRM) acquisition. Figure 1 shows a comparison between indoor air sample acquired using FS and t-SRM modes. FS mode allowed screening for all the compounds in the indoor air samples, whereas the t-SRM acquisition provided sensitivity and selectivity to detect and quantify specific analytes of interest with high confidence.

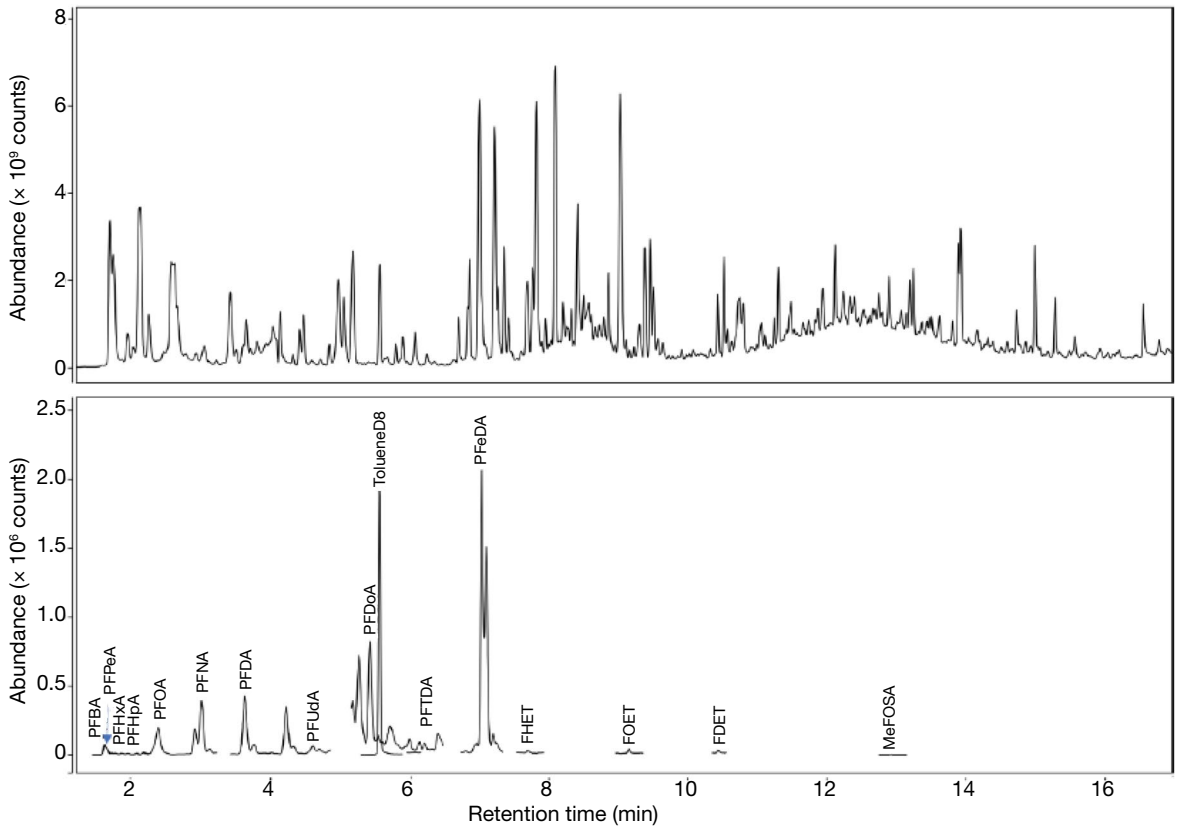


Figure 1. Example of indoor air sampled in a workplace environment showing the complexity of the matrix in FS acquisition (upper trace) versus the high selectivity and sensitivity of t-SRM acquisition for target components

A Markes International Micro-Chamber/Thermal Extractor (µ-CTE) was used to evaluate the PFAS emission from a child's waterproof coat, as an everyday used item. The µ-CTE is a practical tool for determining representative emission or odor profiles from materials, identifying emission sources, and simulating aging or formulation processes. It allows simultaneous collection of volatile and semi-volatile organic compounds from many types of solid and liquid samples and traps the released vapors on sorbent tubes through a simplified operation. No additional sample preparation is required, as demonstrated from the workflow reported in Figure 2. TD100-xr and GC-MS/MS experimental conditions optimized in this study together with the complete list of target compounds, including the t-SRM transitions, are detailed in Table 1 and Table 2, respectively.

Data acquisition, processing, and reporting

Data was acquired, processed, and reported using Thermo Scientific™ Chromeleon™ Chromatography Data System (CDS) software, version 7.3. Integrated control of the TD100-xr instrument ensures full automation of the analytical workflow from tube desorption to data acquisition, combined with an intuitive user interface for data analysis, processing, customizable reporting, and storage in compliance with the Federal Drug Administration Title 21 Code of Federal Regulations Part 11 (Title 21 CFR Part 11). Figure 3 shows the Chromeleon CDS method editor wizard for the TD100-xr thermal desorber.

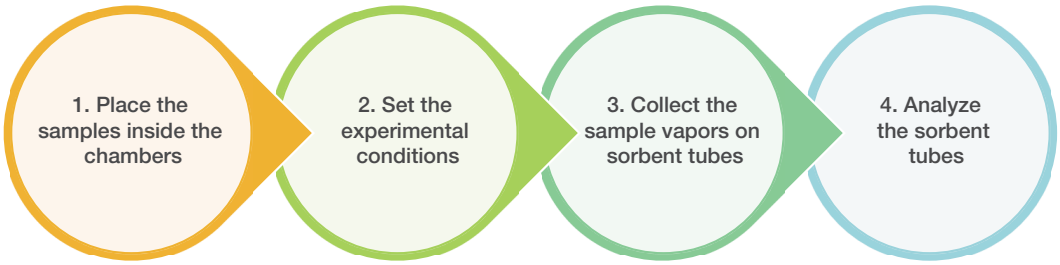


Figure 2. µ-CTE sampling workflow

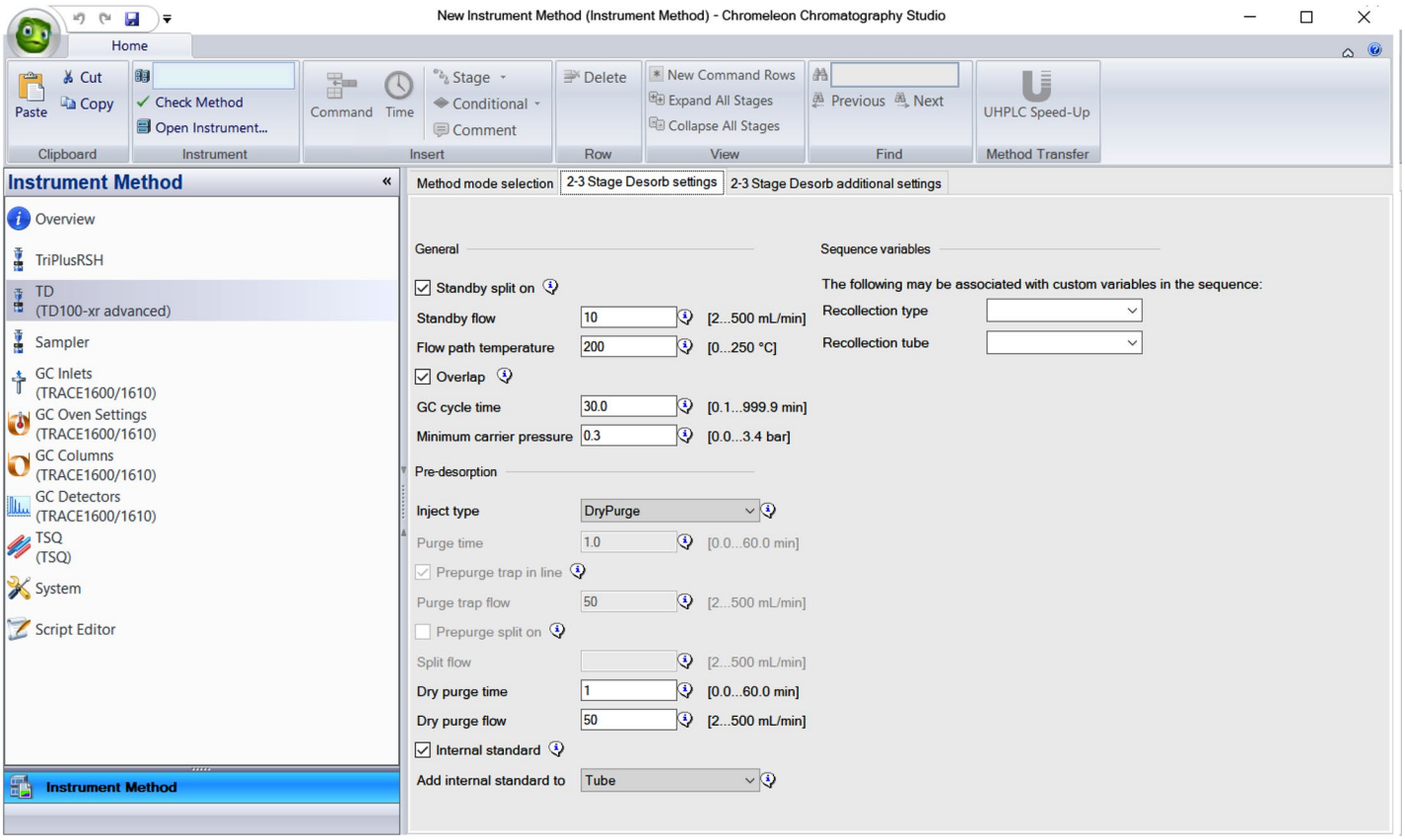
Table 1. TD100-xr Advanced and GC-MS/MS experimental conditions for the analysis of PFAS in indoor air

Markes International TD100-xr Advanced parameters	
Tube type	PFAS Extended volume tubes (P/N C3-AXX-5426)
Flow path temperature (°C)	200
Automatic dry purge	1 min at 50 mL/min
Tube desorption	300 °C for 10 min at 50 mL/min
Trap purge	1 min at 50 mL/min
Focusing trap	PFAS focusing trap (P/N U-T24PFAS-2S)
Focusing trap low temperature (°C)	-30
Elevated trap purge temperature (°C)	25
Focusing trap high temperature (°C)	300 (4 min)
Trap heat rate	Max
Outlet split	6:1

TRACE 1610 GC parameters	
Oven temperature program	
Temperature (°C)	35
Hold time (min)	2
Rate (ºC/min)	15
Temperature 2 (°C)	280
Hold time (min)	5
GC run time (min)	23.33
Carrier gas	He
Carrier flow (mL/min)	1.2
Column	
TraceGOLD TG-200MS	30 m, 0.25 mm, 1.0 µm (P/N 26084-2960)

TSQ 9610 mass spectrometer parameters	
Transfer line temperature (°C)	280
Ion source type and temperature (°C)	AEI, 300
Ionization type	EI
Emission current (µA)	50
Aquisition mode	FS combined with timed-SRM
FS mass range (*m/z*)	35–650
Tuning parameters	AEI Smart Tune
Collision gas and pressure (psi)	Argon at 70

A



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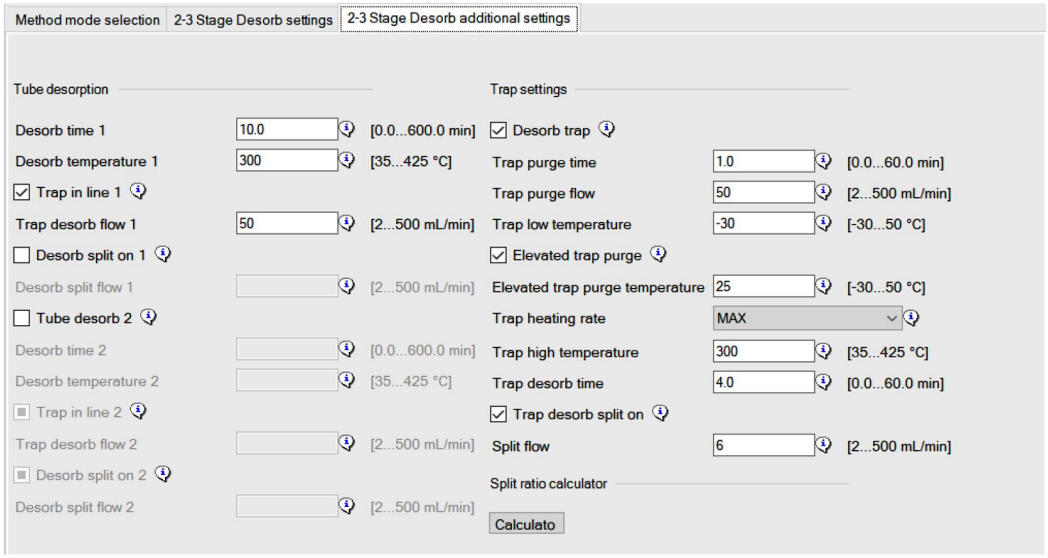

Figure 3. Chromeleon CDS browser showing the method editor wizard for the TD100-xr thermal desorption unit: (A) 2-3 Stage Desorb settings and (B) additional settings

Standard and sample preparation

Standard preparation

Individual component standards were purchased from Wellington Laboratories Inc, Canada, at a concentration of 50 ng/µL, except for the PFCAs, which were available as a mixture at 2 ng/µL and used as a stock standard. The individual component standards were combined and diluted to obtain the working standard solutions ranging from 10 to 5,000 pg/µL, which were used to assess the method performance. A calibration curve was prepared by using a Markes International™ Calibration Solution Loading Rig (CSLR™) to spike 1 µL of each standard onto the sorbent tubes in a flow of nitrogen at 100 mL/min and purge the tubes for 60 min to remove methanol. Up to 20 tubes can be purged simultaneously using the Markes International™ TC-20™ unit, significantly speeding up the spike process. The TC-20 was also used to re-condition the sorbent tubes in nitrogen prior to sampling, avoiding the use of analytical instrument time and consumption of carrier gas.

Sample preparation

Indoor air samples were collected from a workplace (sampled air volume: 20 L) and a residential building (sampled air volume: 70 L) at a flow rate of 100 mL/min using a Markes International™ ACTI-VOC PLUS™ constant flow sampling. Toluene-d8 gaseous internal standard at 100 ppb in nitrogen was automatically added by using the ISDP accessory of the TD100-xr and used to monitor the process for sample integrity. The IS (2 mL) was added to the sample tubes by using a 1 mL loop pressurized to 15 psi.

To evaluate possible emissions from everyday use items, some pieces of water-resistant child's coat were cut and weighed into aluminum sample boats before being placed in the Markes International Micro-Chamber/Thermal Extractor. Once sealed into individual microchambers, the samples were incubated at a user-defined temperature and purged with gas, with emitted vapors being swept into the connected sorbent tubes. Although pure air is normally used as the purge gas (dry or humidified) to simulate real-world conditions, nitrogen was chosen in this case to evaluate emissions without oxidation.

Results and discussion

Instrument background assessment

One of the main challenges of PFAS analysis lies in the low detection limits that must be achieved as these compounds occur at low concentration in both indoor and outdoor air. Dedicated PFAS tubes packed with sorbent material (Markes International PFAS Extended volume tubes, P/N C3-AAXX-5426) have been designed to allow effective sample pre-concentration to detect such low levels of PFAS. The instrument background was assessed by desorbing an unsampled focusing trap applying the previously described conditions (Table 1). No elevated background was detected for any of the target analytes, demonstrating that the flow path of the instrument was inherently PFAS-free. Multiple sorbent tubes were then assessed to determine the analytical method blank. Five of the target compounds were found to be at or just above half the lowest concentration standard ("challenge level").[3] The calculated method detection limit (MDL) for these compounds reflects the level at which they were found in the method blank.

Chromatography

PFAS are a group of synthetic compounds with different chemical and physical properties, therefore the proper column choice is essential to get adequate resolution and sensitivity for both qualitative and quantitative analysis. The polar phase of the TraceGOLD TG-200MS column (trifluoropropylmethyl polysiloxane) provides a unique selectivity for fluorinated compounds, for an adequate chromatographic separation of the targets combined with Gaussian peak shapes, as shown in Figure 4 for a sorbent tube spiked with 19 investigated PFAS at mid-point calibration level (corresponding to 500 pg on-tube).

Linearity

Calibration curves were prepared by spiking 1 µL of the working solution ranging from 10 to 5,000 pg/µL on the sorbent tubes. A minimum of six calibration points were used for each of the compounds. All compounds showed a linear trend within the used calibration ranges with coefficient of determination (R^2) > 0.990 as reported in Table 2.

Method detection limits

The concentration of individual PFAS species in indoor air varies depending on the sources; overall published studies on PFAS indoor air monitoring have generally determined individual compounds at levels above 600 ng/m^3.[4] The method detection limit (MDL) for this study was calculated by comparing seven method blanks with seven sorbent tubes that were spiked with a standard at a "challenge level" in accordance with U.S. EPA guidance.[3] Using this approach, the average method detection limit was 16 pg. Considering that workplace indoor air was sampled at a volume of 20 L, the average MDL is 780 pg/m^3 or approximately 0.8 ng/m^3. Detailed results can be found in Table 2.

Table 2. List of target compounds as well as retention times (RT), quantitation ions, coefficient of determination (R^2), peak area %RSD (n=7), and calculated MDLs

Compound	RT (min)	Quantitation ion (*m/z*)	Calibration range (pg/µL)	R^2	Peak area %RSD (n=7)	Calculated MDL (pg)	Calculated MDL (20 L, pg/m³)
Perfluoroalkyl carboxylic acids (PFCAs)							
Perfluoro-*n*-butanoic acid (PFBA)	1.59	131/69	10–2000	0.9985	4.52	5	250
Perfluoro-*n*-pentanoic acid (PFPeA)	1.63	131/69	10–2000	0.9966	3.80	2	100
Perfluoro-*n*-hexanoic acid (PFHxA)	1.73	131/69	10–2000	0.9970	3.25	23	1150
Perfluoro-*n*-heptanoic acid (PFHpA)	1.93	131/69	10–2000	0.9981	2.42	3	150
Perfluoro-*n*-octanoic acid (PFOA)	2.33	131/69	10–2000	0.9986	2.00	2	100
Perfluoro-*n*-nonanoic acid (PFNA)	2.89	131/69	10–2000	0.9983	1.48	46	2300
Perfluoro-*n*-decanoic acid (PFDA)	3.66	131/69	10–2000	0.9978	2.48	27	1350
Perfluoro-*n*-undecanoic acid (PFUdA)	4.60	131/69	10–2000	0.9974	3.67	4	200
Perfluoro-*n*-dodecanoic acid (PFDoA)	5.40	131/69	10–2000	0.9975	2.71	21	1050
Perfluoro-*n*-tridecanoic acid (PFTrDA)	6.22	131/69	10–2000	0.9974	3.00	3	150
Perfluoro-*n*-tetradecanoic acid (PFTeDA)	6.96	131/69	10–2000	0.9975	3.01	2	100
Fluorotelomer carboxylic acids (FTCAs)							
2-Perfluorohexyl ethanoic acid (6:2) (FHEA)	3.97	131/69	100–5000	0.9953	5.75	64	3200
2-Perfluorooctyl ethanoic acid (8:2) (FOEA)	5.90	131/69	100–5000	0.9983	2.65	62	2600
Fluorotelomer alcohols (FTOHs)							
2-Perfluorobutyl ethanol (4:2) (FBET)	6.01	95/69	10–5000	0.9951	4.10	13	650
2-Perfluorohexyl ethanol (6:2) (FHET)	7.67	95/69	10–5000	0.9971	2.61	18	900
2-Perfluorooctyl ethanol (8:2) (FOET)	9.13	95/69	10–5000	0.9963	3.99	4	200
2-Perfluorodecyl ethanol (10:2) (FDET)	10.41	95/69	10–5000	0.9937	4.08	6	300
Perfluorooctanesulfonamides (FOSAs)							
N-Methylperfluoro-1-octanesulfonamide Me-(FOSA)	12.88	94/30	10–5000	0.9953	0.83	1	50
N-Ethylperfluoro-1-octanesulfonamide Et-(FOSA)	13.19	108/80	10–5000	0.9953	5.29	1	50

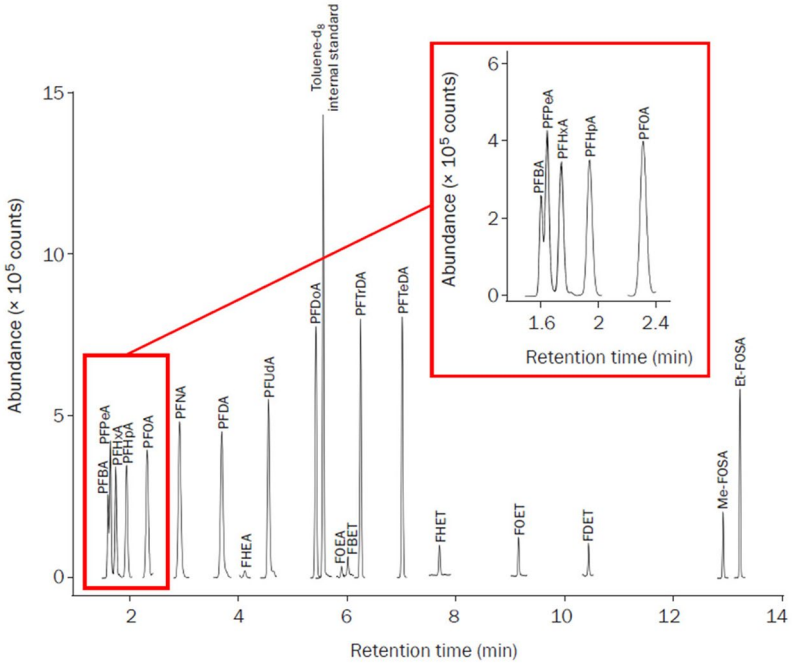

Figure 4. Example of t-SRM acquisition for PFAS standard spiked on a sorbent tube at a mid-point calibration level (corresponding to 500 pg on-tube). The inset shows a close-up view of the chromatogram for the first five compounds, which are perfluoroalkylcarboxylic acids (PFCAs).

Analysis of indoor air in workplaces

Indoor samples from workplaces were collected in spaces dedicated to offices (singular occupancy and open plan), analytical laboratories, kitchen areas, storage areas, and a factory. The analyzed samples show that nearly all the target compounds were found in at least one of the sampling locations, with the exception of FBET and Et-FOSA. The class of PFAS compounds with the highest concentrations was the carboxylic acids – PFOA, PFDA, PFDoA, and PFTeDA.

Figure 5 shows the comparison of four workplace environments, the location with the highest overall PFAS levels was the corridor (156.95 ng/m^3) and the lowest was the storeroom containing painted materials (38.35 ng/m^3). The total PFAS concentration in the analytical laboratory was 79.35 ng/m^3, which was similar to the single-occupancy office environment (89.10 ng/m^3). Detailed results are reported in Appendix 1. The presence of the target compounds in the laboratory makes clear the need for a stringent blank regime instrumentation to avoid contamination and maintain sample integrity. The analytical caps (with DiffLok™ technology) stay on the sorbent throughout an automated sequence preventing both artifact ingress and analyte loss.

Analysis of indoor air in a residential property

Indoor air samples were taken from a residential property that was undergoing major renovations. PFAS compounds are known to be included in building materials such as paints, flooring, sealants and adhesives, glass and ceramics, and even lightbulbs.[5] This is in addition to the PFAS found in everyday items in the home. An example of compounds detected in the residential air sample is shown in Figure 6. Compared to the workplace environment, the fluorotelomer alcohols (FBET, FHET, FOET, and FDET) had the highest concentrations, and fewer other individual PFAS species were identified. The total concentration of identified PFAS was also significantly lower than in the workplace environment (11.15 ng/m^3 vs. an average of 90.94 ng/m^3). Unlike the office air samples, residential air showed the FTOHs and FOSAs more prominent than the PFCAs. The PFCAs detected consisted of the most volatile species, where acids of chain length greater that C9 were not detected. Detailed results can be found in Appendix 2.

Evaluation of emissions from an everyday use item

To evaluate the emissions of PFAS from an everyday use material, a child's waterproof coat was analyzed using the Markes International Micro-Chamber/Thermal Extractor. Samples of the coat were prepared and tested using the μ-CTE as described previously. Tests were carried out at ambient temperature to simulate the indoor environment (refer to the EN ISO 16000-series methods and other similar standards[8–10]). The compound with the highest concentration in the sample was the fluorotelomer alcohol 2-perfluorooctyl ethanol (FOET) (8:2), with 3.9 ng being released per gram of material at ambient temperature as shown in Figure 7. The bulk emission rate was then calculated by dividing the concentration by the sampling time in minutes. For FTOH 8:2 (FOET), the emission rate was 0.131 ng/g/min. Table 3 summarizes the detected PFAS compounds as well as their concentration and the emission rate. The emission rate is crucial as it would form the basis of any emissions limits placed on PFAS-containing materials in the future.

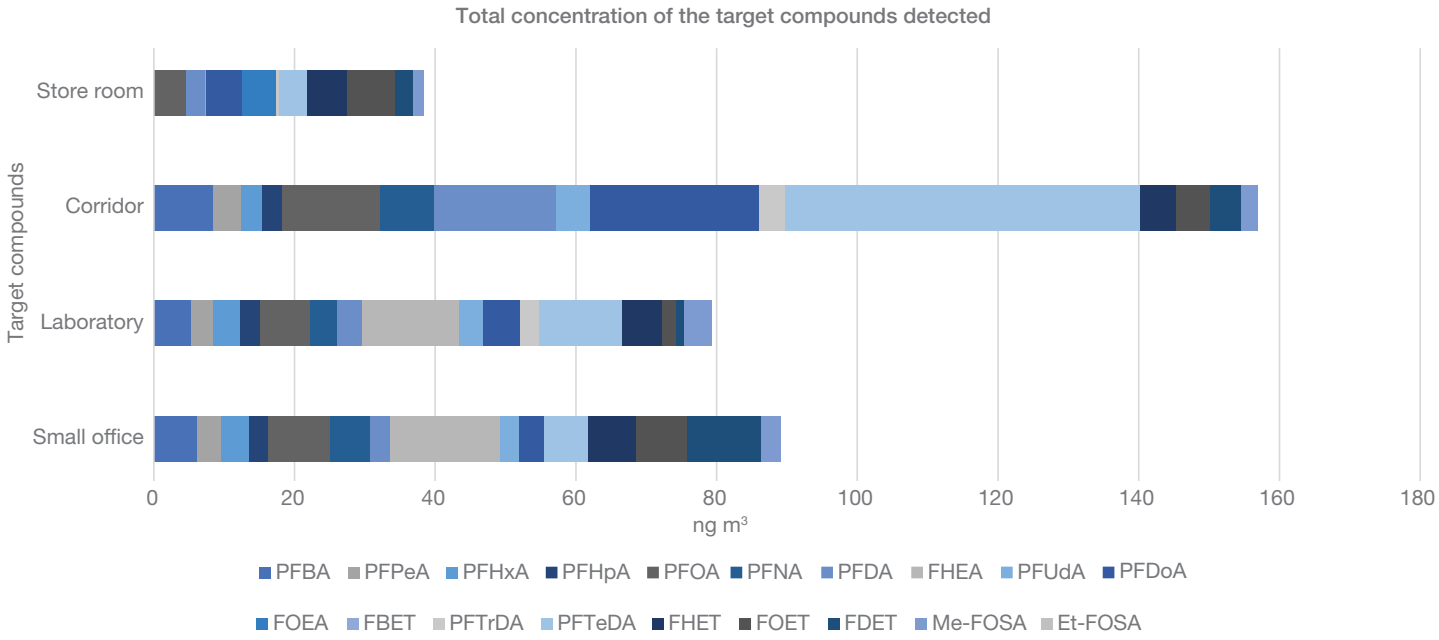

Figure 5. Total concentration of each of the target compounds detected in each individual workspace. The concentration of PFTeDA quantified in the air of the corridor (50 ng/m^3) contributes greatly to the total concentration detected in that environment.

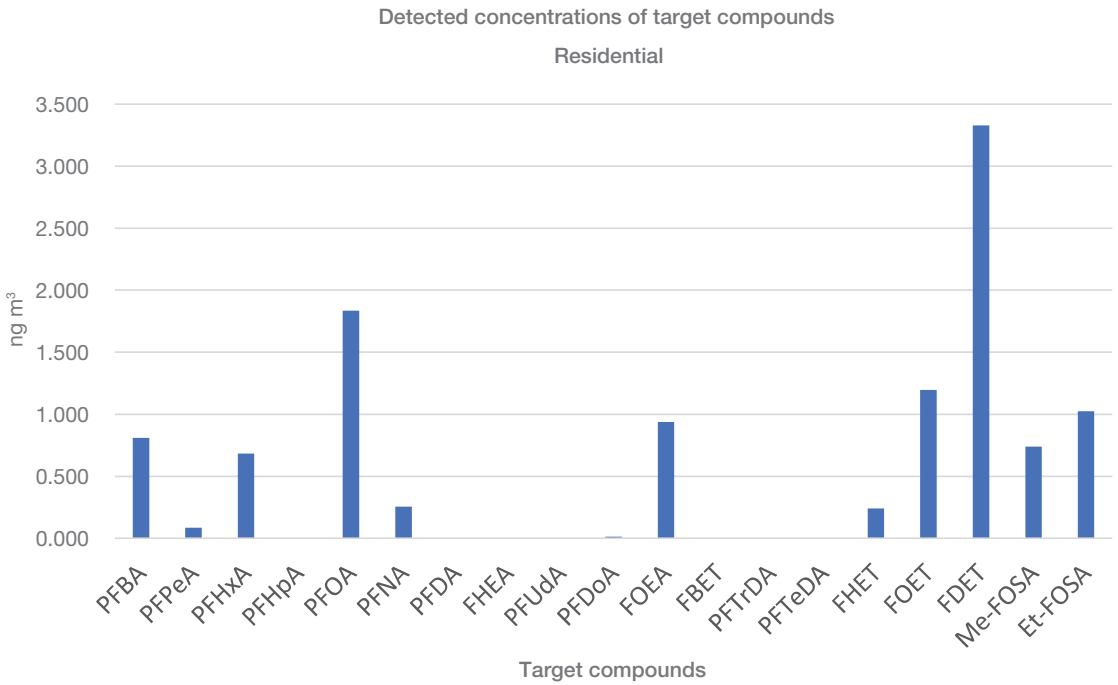

Figure 6. Compounds detected in the residential air sample (sampled air volume: 70 L)

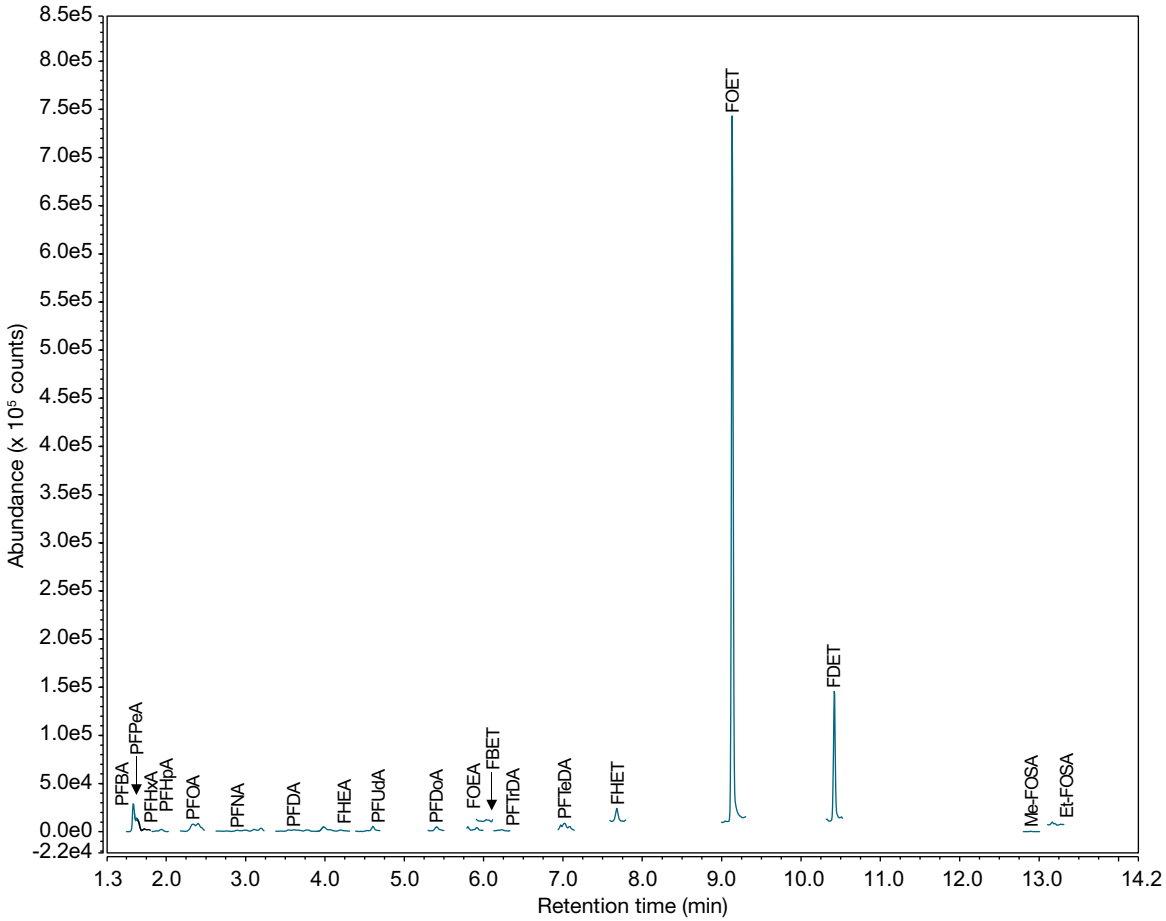

Figure 7. SRM chromatogram for the child's waterproof coat at ambient temperature. Although other PFAS are present, the highest emissions are clearly from FTOH 8:2 (FOET) and FTOH 10:2 (FDET).

Table 3. Detected PFAS compounds emitted from waterproof child's coat along with calculated concentration and emission rate

Compound	RT (min)	Amount (ng/g)	Emission rate (ng/g/min)
Perfluoroalkyl carboxylic acids (PFCAs)			
Perfluoro-*n*-butanoic acid (PFBA)	1.59	0.045	0.002
Perfluoro-*n*-pentanoic acid (PFPeA)	1.63	0.008	0.000
Perfluoro-*n*-hexanoic acid (PFHxA)	1.73	ND	ND
Perfluoro-*n*-heptanoic acid (PFHpA)	1.93	ND	ND
Perfluoro-*n*-octanoic acid (PFOA)	2.33	0.034	0.001
Perfluoro-*n*-nonanoic acid (PFNA)	2.89	ND	ND
Perfluoro-*n*-decanoic acid (PFDA)	3.66	ND	ND
Perfluoro-*n*-undecanoic acid (PFUdA)	4.60	ND	ND
Perfluoro-*n*-dodecanoic acid (PFDoA)	5.40	0.006	0.000
Perfluoro-*n*-tridecanoic acid (PFTrDA)	6.22	ND	ND
Perfluoro-*n*-tetradecanoic acid (PFTeDA)	6.96	ND	ND
Fluorotelomer carboxylic acids (FTCAs)			
2-Perfluorohexyl ethanoic acid (6:2) (FHEA)	3.97	ND	ND
2-Perfluorooctyl ethanoic acid (8:2) (FOEA)	5.90	0.126	0.004
Fluorotelomer alcohols (FTOHs)			
2-Perfluorobutyl ethanol (4:2) (FBET)	6.01	ND	ND
2-Perfluorohexyl ethanol (6:2) (FHET)	7.67	ND	ND
2-Perfluorooctyl ethanol (8:2) (FOET)	9.13	3.943	0.131
2-Perfluorodecyl ethanol (10:2) (FDET)	10.41	0.814	0.027
Perfluorooctanesulfonamides (FOSAs)			
N-Methylperfluoro-1-octanesulfonamide Me-(FOSA)	12.88	0.042	0.001
N-Ethylperfluoro-1-octanesulfonamide Et-(FOSA)	13.19	ND	ND

Conclusions

The results obtained in these experiments demonstrate that the TD100-xr Advanced coupled to the TRACE 1610 GC and TSQ 9610 mass spectrometer equipped with AEI source delivers reliable analytical performance for analysis of PFAS in indoor air.

- The fully integrated instrument control of the TD100-xr in Chromeleon CDS ensures easy and straightforward method settings, sequence set-up, and data review within a few mouse clicks.
- The use of the µCTE is ideal when analyzing solid samples as it removes the need for extensive sample preparation, reducing cost per sample and making laboratory operations easier and safer.
- The pre-concentration stages of the TD sampling technique combined with the highly sensitive TSQ 9610 mass spectrometer with AEI source ensured high sensitivity with average MDL of 780 pg/m^3 calculated considering a sample volume of 20 L. Moreover, the TD100-xr provides efficient purging and heating of the sample flow path, assuring robustness and reliability for everyday analysis with no carryover effects.

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Appendix 1

Table A1. Calculated concentrations of PFAS across four sites in a workplace

Compound	RT (min)	Amount (pg/m³)			
		Office	Laboratory	Store	Corridor
Perfluoroalkyl carboxylic acids (PFCAs)					
Perfluoro-*n*-butanoic acid (PFBA)	1.59	6.25	5.25	ND	8.40
Perfluoro-*n*-pentanoic acid (PFPeA)	1.63	3.30	3.25	ND	3.95
Perfluoro-*n*-hexanoic acid (PFHxA)	1.73	4.10	3.75	ND	3.10
Perfluoro-*n*-heptanoic acid (PFHpA)	1.93	2.60	2.85	ND	2.85
Perfluoro-*n*-octanoic acid (PFOA)	2.33	8.90	7.15	4.55	13.85
Perfluoro-*n*-nonanoic acid (PFNA)	2.89	5.55	3.85	ND	7.75
Perfluoro-*n*-decanoic acid (PFDA)	3.66	2.95	3.50	2.80	17.25
Perfluoro-*n*-undecanoic acid (PFUdA)	4.60	2.75	3.30	0.05	4.95
Perfluoro-*n*-dodecanoic acid (PFDoA)	5.40	3.45	5.35	5.10	23.95
Perfluoro-*n*-tridecanoic acid (PFTrDA)	6.22	ND	2.65	0.35	3.65
Perfluoro-*n*-tetradecanoic acid (PFTeDA)	6.96	6.30	11.80	4.00	50.55
Fluorotelomer carboxylic acids (FTCAs)					
2-Perfluorohexyl ethanoic acid (6:2) (FHEA)	3.97	15.60	13.85	ND	ND
2-Perfluorooctyl ethanoic acid (8:2) (FOEA)	5.90	ND	ND	4.95	ND
Fluorotelomer alcohols (FTOHs)					
2-Perfluorobutyl ethanol (4:2) (FBET)	6.01	ND	ND	ND	ND
2-Perfluorohexyl ethanol (6:2) (FHET)	7.67	6.85	5.75	5.75	5.05
2-Perfluorooctyl ethanol (8:2) (FOET)	9.13	7.30	1.90	6.75	4.90
2-Perfluorodecyl ethanol (10:2) (FDET)	10.41	10.40	1.20	2.50	4.45
Perfluorooctanesulfonamides (FOSAs)					
N-Methylperfluoro-1-octanesulfonamide Me-(FOSA)	12.88	2.80	3.95	1.55	2.30
N-Ethylperfluoro-1-octanesulfonamide Et-(FOSA)	13.19	ND	ND	ND	ND
Total PFAS		**89.10**	**79.35**	**38.35**	**156.95**

Appendix 2

Table A2. Concentration of compounds found in residential air (sampled air volume: 70 L)

Compound	RT (min)	Amount (ng/m³)
Perfluoroalkyl carboxylic acids (PFCAs)		
Perfluoro-*n*-butanoic acid (PFBA)	1.59	0.81
Perfluoro-*n*-pentanoic acid (PFPeA)	1.63	0.09
Perfluoro-*n*-hexanoic acid (PFHxA)	1.73	0.68
Perfluoro-*n*-heptanoic acid (PFHpA)	1.93	ND
Perfluoro-*n*-octanoic acid (PFOA)	2.33	1.84
Perfluoro-*n*-nonanoic acid (PFNA)	2.89	0.26
Perfluoro-*n*-decanoic acid (PFDA)	3.66	ND
Perfluoro-*n*-undecanoic acid (PFUdA)	4.60	ND
Perfluoro-*n*-dodecanoic acid (PFDoA)	5.40	0.01
Perfluoro-*n*-tridecanoic acid (PFTrDA)	6.22	ND
Perfluoro-*n*-tetradecanoic acid (PFTeDA)	6.96	ND
Fluorotelomer carboxylic acids (FTCAs)		
2-Perfluorohexyl ethanoic acid (6:2) (FHEA)	3.97	ND
2-Perfluorooctyl ethanoic acid (8:2) (FOEA)	5.90	0.94
Fluorotelomer alcohols (FTOHs)		
2-Perfluorobutyl ethanol (4:2) (FBET)	6.01	ND
2-Perfluorohexyl ethanol (6:2) (FHET)	7.67	0.24
2-Perfluorooctyl ethanol (8:2) (FOET)	9.13	1.20
2-Perfluorodecyl ethanol (10:2) (FDET)	10.41	3.33
Perfluorooctanesulfonamides (FOSAs)		
N-Methylperfluoro-1-octanesulfonamide Me-(FOSA)	12.88	0.74
N-Ethylperfluoro-1-octanesulfonamide Et-(FOSA)	13.19	1.02
Total PFAS		**11.15**

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