

**ADSORPTION STUDIES OF FLUOROTELOMER
OLEFIN ONTO GRANULAR ACTIVATED
CARBON, NON-ION AND
ION EXCHANGE RESINS**

WAN NURSYAFIQAH BINTI WAN ZAMRI

**MASTER OF SCIENCE
(CHEMISTRY)**

**UNIVERSITI PERTAHANAN NASIONAL
MALAYSIA**

2024

**ADSORPTION STUDIES OF FLUOROTELOMER OLEFIN ONTO
GRANULAR ACTIVATED CARBON, NON-ION AND
ION EXCHANGE RESINS**

WAN NURSYAFIQAH BINTI WAN ZAMRI

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional
Malaysia, in fulfilment of the requirements for the Degree of Master of Science
(Chemistry)

2024

ABSTRACT

Introduction of fluorotelomer into the industry as a replacement for per- and polyfluoroalkyl substances (PFAS) has raised global concern due to its widespread dispersion and potential persistency, bioaccumulation, and toxicity. Adsorption has been recognized as an effective method for removing PFAS from water, however there are lack of studies focusing on fluorotelomer. This study aims to enhance the understanding of fluorotelomer olefin (FTO) adsorption onto different adsorbents, providing valuable insights into potential strategies to eliminate FTO from water systems. Various adsorbents including granular activated carbon (GAC), non-ion exchange resin (XAD-4), and ion exchange resin (IRA958) were examined for adsorption capacity, kinetics, and isotherms under different conditions: adsorbent dosages, contact times, and FTO initial concentrations. Scanning electron microscopy (SEM) images demonstrate that the roughness surface of GAC and smooth surface of XAD-4 remained the same after the adsorption. However, foreign substances were observed on the smooth and cracked surface of IRA958. Brunauer-Emmet-Teller (BET) measurement displayed large surface area of XAD-4 ($860.8548 \text{ m}^2/\text{g}$) followed by GAC ($544.1870 \text{ m}^2/\text{g}$) and IRA958 ($2.0381 \text{ m}^2/\text{g}$). FTO was detected and quantified using gas chromatography-mass spectrometry (GC-MS). The adsorption of FTO on all adsorbents reached equilibrium within 5 h and the data were best-fitted to pseudo-second-order kinetics model ($R^2 > 0.99$). Meanwhile, Freundlich isotherm model was found to be suitable for describing FTO adsorption, with GAC exhibiting the highest adsorption capacity ($K_f = 3.0853$), followed by IRA958 ($K_f = 3.0400$) and XAD-4 ($K_f = 0.0009$). The findings suggest that the adsorption mechanism of

FTO onto adsorbents is characterized by multilayer and chemisorption behavior. Desorption study reveals that FTO was not able to desorb from the adsorbent's surface using either methanol, ethanol, or n-hexane. Removal of FTO remain high (>80%) with or without the presence of interfering compounds (FTI, FTOH and PFHxI), under optimum adsorption conditions: 1.25 mg adsorbent dosage and 5 h contact time with initial concentration of FTO 100 mg/L and above. The findings from this study have shown the potential of GAC, XAD-4 and IRA958 to be used as adsorbents in water treatment plants to remove FTO from water, hence improving the overall quality of water and environment.

ABSTRAK

Pengenalan fluorotelomer ke dalam industri sebagai pengganti sebatian perfluoroalkil (PFAS) telah menimbulkan kebimbangan global disebabkan penyebaran meluas dan potensi keberkekalan, bioakkumulasi, dan toksisiti. Penjerapan telah dikenal pasti sebagai kaedah yang berkesan untuk menyingkirkan PFAS dari air, namun terdapat kekurangan kajian yang memberi tumpuan terhadap sebatian fluorotelomer. Kajian ini bertujuan untuk meningkatkan pemahaman mengenai penjerapan fluorotelomer olefin (FTO) ke atas pelbagai penjerap yang berbeza, di mana kajian ini dapat membantu memberikan pemahaman yang berguna terhadap strategi yang bersesuaian dalam menyingkir FTO daripada sistem pengairan. Pelbagai penjerap termasuk butir karbon teraktif (GAC), resin pertukaran bukan ion (XAD-4), dan resin pertukaran ion (IRA958) telah dikaji bagi mengetahui kapasiti penjerapan, kinetik dan isoterma di bawah kondisi yang berbeza: dos penjerap, masa sentuhan, dan kepekatan awal FTO. Imej mikroskopi imbas elektron (SEM) menunjukkan bahawa permukaan kasar GAC dan permukaan licin XAD-4 kekal sama selepas penjerapan. Walau bagaimanapun, bahan asing telah diperhatikan muncul di permukaan licin dan retak IRA958. Pengukuran Brunauer-Emmet-Teller (BET) menunjukkan luas permukaan terbesar XAD-4 (860.8548 m²/g) diikuti oleh GAC (544.1870 m²/g) dan IRA958 (2.0381 m²/g). FTO telah dikesan dan dianalisis menggunakan spektrometri jisim gas kromatografi (GC-MS). Dari segi kinetik penjerapan, kebanyakan penjerapanan FTO pada penjerap mencapai keseimbangan dalam masa 5 jam di mana semua penjerap dideskripsikan dengan baik menggunakan model kinetik pseudo-kedua ($R^2 > 0.99$). Sementara itu, model isoterma Freundlich

didapati sesuai untuk menerangkan penjerapan FTO, di mana GAC menunjukkan kapasiti penjerapan tertinggi ($K_f = 3.0853$), diikuti oleh IRA958 ($K_f = 3.0400$) dan XAD-4 ($K_f = 0.0009$). Kajian ini mencadangkan bahawa interaksi kuat antara molekul FTO dan permukaan penjerap menghasilkan pembentukan lapisan FTO yang berganda, melibatkan mekanisme penjerapan berlapis dan kimi-serapan. Hasil kajian penyahjerapan mendapati FTO tidak dapat disingkirkan dari permukaan penjerap menggunakan sama ada metanol, etanol atau n-heksana. Selain itu, penyingkiran FTO masih kekal tinggi (>80%) walaupun dengan kehadiran atau tanpa kehadiran sebatian mengganggu yang lain (FTI, FTOH dan PFHxI) di bawah kondisi penjerapan optimum: dos penjerap 1.25 mg dan masa sentuhan 5 jam pada kepekatan FTO 100 mg/L and ke atas. Penemuan dari kajian ini telah menunjukkan potensi GAC, XAD-4 dan IRA958 untuk digunakan sebagai penjerap dalam loji rawatan air untuk menyingkirkan FTO dari sistem perairan, dengan itu mampu meningkatkan kualiti air dan alam sekitar.

ACKNOWLEDGEMENTS

In the name of Allah, Most Merciful. I am deeply grateful to Almighty Allah for guiding me through the challenges of the past three years. First and foremost, I extend my heartfelt gratitude to my parents, Noorulaini Binti Hamid and Wan Zamri bin Wan Ibrahim, for their unconditional love, endless support, and constant prayers. Special thanks to my siblings for standing by me with unwavering support and encouragement.

I am indebted to my principal supervisor, Dr. Nor Laili-Azua Jamari, for her exceptional guidance, patience, and unwavering belief in my abilities. My heartfelt thanks also go to my co-supervisors, Prof. Dr. Ong Keat Khim and Dr. Norherdawati Kasim, for their valuable insights and support throughout this journey. Additionally, I am grateful to Encik Syed Mohd Shafiq Syed Ahmad and Dr. Muhammad Faizan A. Shukor for their guidance and assistance in completing my research. To my friends and colleagues, your support, encouragement, and understanding have been invaluable to me, and I am deeply grateful for your presence in my life.

I extend my sincere appreciation to the Ministry of Higher Education for their financial support through the Fundamental Research Grant Scheme (FRGS/1/2020/STG04/UPNM/03/1). Lastly, I would like to express my gratitude to all the staff, especially those from the Centre for Defence Foundation Studies and Centre for Graduate Studies, for their unwavering assistance, guidance, and patience.

APPROVAL

The Examination Committee has met on **25 July 2024** to conduct the final examination of **Wan Nursyafiqah Binti Wan Zamri** on his degree thesis entitled '**Adsorption studies of fluorotelomer olefin onto granular activated carbon, non-ion and ion exchange resin**'.

The committee recommends that the student be awarded the of Master of Science (Chemistry).

Members of the Examination Committee were as follows.

Dr. Safura binti Taufik

Centre of Defence Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Chairman)

Prof. Madya Dr. Noor Azilah binti Mohd Kasim

Centre of Defence Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Dr. Yatim Lailun Ni'mah

Faculty of Science and Data Analytics
Institut Tek. Sepuluh Nopember Surabaya, Indonesia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Chemistry)**. The members of the Supervisory Committee were as follows.

Dr Nor Laili-Azua Binti Jamari

Centre of Defence Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Prof. Dr. Ong Keat Khim

Centre of Defence Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Norherdawati Binti Kasim

Centre of Defence Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : Wan Nursyafiqah Binti Wan Zamri
Date of birth : 19 July 1997
Title : Adsorption studies of fluorotelomer olefin onto granular activated carbon, non-ion and ion exchange resin
Academic session : 2024/2025

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

- CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)*
- RESTRICTED** (Contains restricted information as specified by the organisation where research was done)*
- OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

Signature

**Signature of Supervisor/Dean of CGS/

970719-03-5990

Dr Nor Laili-Azua Binti Jamari

IC/Passport No.

**Name of Supervisor/Dean of CGS/

Date:

Date:

*If the thesis is CONFIDENTIAL OR RESTRICTED, please attach the letter from the organisation with period and reasons for confidentiality and restriction.

** Witness

TABLE OF CONTENTS

	TITLE	PAGE
	ABSTRACT	ii
	ABSTRAK	iv
	ACKNOWLEDGEMENTS	vi
	APPROVAL	vii
	APPROVAL	viii
	DECLARATION OF THESIS	ix
	TABLE OF CONTENTS	x
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF EQUATIONS	xviii
	LIST OF ABBREVIATIONS	xix
	LIST OF SYMBOLS	xxiii
	LIST OF APPENDICES	xix
CHAPTER 1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem statement	6
	1.3 Objectives	7
	1.4 Scope of works	8
	1.5 Thesis overview	9
CHAPTER 2	LITERATURE REVIEW	11
	2.1 Per- and polyfluoroalkyl substances (PFAS)	11
	2.1.1 Fluorotelomer	17
	2.1.2 Fluorotelomer olefin (FTO)	20
	2.2 PFAS removal techniques	25
	2.2.1 Sonochemical degradation	26
	2.2.2 Bioremediation	27
	2.2.3 Thermal degradation	28
	2.2.4 Advance oxidation process	29
	2.2.5 Membrane filters	30
	2.2.6 Adsorption	32
	2.2.6.1 Adsorption by activated carbon (AC)	32
	2.2.6.2 Adsorption by ion exchange resin	36
	2.2.6.3 Adsorption by non-ion exchange resin	39
	2.3 Factor influencing PFAS adsorption	44
	2.3.1 Dosage of adsorbents	44
	2.3.2 Contact time	46
	2.3.3 Initial concentration of adsorbate	47
	2.3.4 Effect of the presence of organic material (OM)	51
	2.4 Adsorption model	53
	2.4.1 Adsorption kinetics	53
	2.4.1.1 Pseudo-first-order (PFO) model	54

	2.4.1.2 Pseudo-second-order (PSO) model	55
	2.4.1.3 Intraparticle diffusion (IPD) model	56
	2.4.2 Adsorption isotherms	59
	2.4.2.1 Langmuir model	60
	2.4.2.2 Freundlich model	60
CHAPTER 3	RESEARCH METHODOLOGY	64
	3.1 Materials	64
	3.2 Adsorbent pretreatment	65
	3.3 Characterization of adsorbents	66
	3.3.1 Scanning Electron Microscopy	66
	3.3.2 Brunauer-Emmett-Teller (BET)	66
	3.4 Preparation of FTO working solution	67
	3.5 Adsorption experiment	67
	3.5.1 Adsorbent dosage	67
	3.5.2 Contact time	68
	3.5.3 Initial concentration of FTO	69
	3.6 Desorption experiment	70
	3.7 Interferences studies	72
	3.8 Analytical method for gas chromatography-mass spectrometry (GC-MS)	73
CHAPTER 4	RESULTS AND DISCUSSIONS	75
	4.1 Adsorbent characterization	75
	4.1.1 Scanning electron microscope (SEM)	76
	4.1.2 Brunauer-Emmett-Teller (BET)	78
	4.2 Gas chromatography-mass spectrometry (GC-MS)	82
	4.2.1 Analytical method and performance	85
	4.2.2 Limit of Detection (LOD) and Limit of Quantitation (LOQ)	86
	4.3 Adsorption studies	87
	4.3.1 Adsorbent dosage	88
	4.3.2 Contact time	89
	4.3.3 Initial concentration	91
	4.4 Adsorption kinetics studies	92
	4.5 Adsorption isotherm studies	97
	4.6 Proposed adsorption mechanism	102
	4.7 Desorption studies	104
	4.8 Interference study	107
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	110
	5.1 Conclusions	110
	5.2 Recommendation for future research	112
	REFERENCES	114
	APPENDICES	136
	BIODATA OF STUDENT	138
	LIST OF PUBLICATIONS	139
	ORAL PRESENTATIONS	141

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Physicochemical characteristics of FTO compounds. Data was collected from a (EPA, 2021) and b (Wang et al., 2011)	23
Table 2.2	Example of adsorption studies of PFAS on various types of adsorbents	41
Table 2.3	Comparative analysis of mechanisms, and respective advantages and disadvantages for GAC, ion exchange and non-ion exchange resins	43
Table 2.4	Summary of adsorbent dosage, contact time and initial concentration of PFAS adsorption onto activated carbon, ion-exchange and non-ion exchange resins. *Remarks for the best optimum conditions	50
Table 2.5	Summary of PFAS adsorption kinetics models from previous studies	59
Table 2.6	Compilation and review of adsorption isotherm studies conducted by previous researchers	63
Table 3.1	Chemicals and materials employed in the study	65
Table 4.1	BET characterization of GAC, XAD-4 and IRA958	81
Table 4.2	Mass to charge ratio and retention time of PFHxI, FTO, FTOH and FTI	83
Table 4.3	Summary data for PFO kinetics model parameters and coefficients	94
Table 4.4	Summary data for PSO kinetics model parameters and coefficients	94

Table 4.5	Summary data for IPD model parameters and coefficients	95
Table 4.6	Comparison between q_e value from experiment and q_e value from PSO model	96
Table 4.7	Summary data for Langmuir isotherm model parameters and coefficients	98
Table 4.8	Data separation factor, R_L , of Langmuir isotherm model based on different initial concentration	98
Table 4.9	Freundlich isotherm parameters and coefficient of determination for adsorption of FTO	100
Table 4.10	Summary of desorption percentage of FTO from adsorbents	105

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1	Fluorotelomer olefin (FTO) molecular structure	4
Figure 2.1	The classification of PFAS, which has been adapted from a specific reference source (Interstate Technology Regulatory Council (ITRC), 2020)	13
Figure 2.2	Example of hydrophilic end group a hydrophobic backbone of PFAS compound	14
Figure 2.3	The process of producing fluorotelomer compounds through the fluorotelomerization method. The illustration was reproduced from (Buck et al., 2011)	20
Figure 2.4	Biodegradation of fluorotelomer pathways which lead to the formation of PFCAs. Illustration adapted from (Wu et al., 2021)	25
Figure 2.5	General structure of AC with certain active groups that could potentially exist on the surface of AC. Figure adapted from (Heidarinejad et al., 2020)	33
Figure 2.6	General structure of ion-exchange resin IRA958	36
Figure 2.7	General structure of non-ion exchange resin, XAD-4	39
Figure 2.8	Adsorption mechanism for (a) PFO, (b) PSO and (c) IPD models	59
Figure 2.9	Comparison between homogeneous monolayer of Langmuir and heterogeneous multilayer of Freundlich adsorption. Adapted from (Knight et al., 2018)	63
Figure 3.1	Experimental schematic diagram illustrating the adsorption process of FTO at varying adsorbent dosages	68

Figure 3.2	Experimental schematic diagram detailing the adsorption process with different contact time	69
Figure 3.3	Adsorption experimental schematic diagram of FTO with different initial concentration	70
Figure 3.4	Desorption experimental schematic diagram of FTO with different solvents	71
Figure 3.5	Experimental schematic diagram of interference study on FTO adsorption with the presence of FTI, FTOH and PFHxI at different concentrations	73
Figure 4.1	SEM image of (a) GAC, (b) XAD-4 and (c) IRA958 before adsorption, while (d) GAC, (e) XAD-4 and (f) IRA958 after the adsorption process	76
Figure 4.2	Pore size distribution of a) GAC b) XAD-4 and c) IRA958	82
Figure 4.3	GC-MS chromatogram in SIM mode of several PFAS standard	84
Figure 4.4	FTO peak from GC-MS characterization in SIM mode	84
Figure 4.5	Calibration curve of FTO peak area vs concentration	85
Figure 4.6	Adsorption capacity of FTO onto different types of adsorbents with different dosage (sorption conditions: different dosage of adsorbents in 100 mg/L FTO for 24 h)	89
Figure 4.7	Best fitted line for adsorption capacity of FTO based on different contact time (sorption conditions: 1.25 mg adsorbents in 100 mg/L FTO for different contact time)	91

Figure 4.8	Adsorption capacity concerning FTO adsorption at various initial concentrations (sorption conditions: 1.25 mg adsorbents in different concentration of FTO for 5 h)	92
Figure 4.9	PFO plot for adsorption of FTO on GAC (■), XAD-4 (●) and IRA958 (▲)	93
Figure 4.10	PSO plot for adsorption of FTO on GAC (■), XAD-4 (●) and IRA958 (▲)	93
Figure 4.11	IPD plot for adsorption of FTO on GAC (■), XAD-4 (●) and IRA958 (▲)	94
Figure 4.12	Langmuir isotherm plot for FTO adsorption on GAC (■), XAD-4 (●) and IRA958 (▲)	97
Figure 4.13	Freundlich isotherm plot for FTO adsorption of FTO on GAC (■), XAD-4 (●) and IRA958 (▲)	100
Figure 4.14	Proposed adsorption mechanism of FTO onto the adsorbent by hydrophobic and Van der Waals interaction	104
Figure 4.15	Desorption percentage of FTO from (a) GAC, (b) XAD-4 and (c) IRA958 in 100 mL of different regeneration solvents (sorption conditions: 1.25 mg of adsorbents in 100 mg/L FTO for 5 h)	106
Figure 4.16	Percentage removal of FTO with the absence and presence of different concentration (0, 50, and 100 mg/L) of (a) PFHxI, (b) FTOH and (c) FTI (sorption conditions: 1.25 mg GAC and IRA958 in 400 mg/L FTO for 5 h)	108

LIST OF EQUATIONS

EQUATION NO.	EQUATION	PAGE
Equation 2.1	$C_n F_{2n+1} - R$	11
Equation 2.2	$\frac{dq_t}{dt} = k_1(q_e - q_t)$	54
Equation 2.3	$\text{Log}(q_e - q_t) = \text{log } q_e - \frac{k_1}{2.303} t$	54
Equation 2.4	$\frac{dq_t}{dt} = k_2(q_e - q_t)^2$	55
Equation 2.5	$\frac{t}{qt} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t$	55
Equation 2.6	$q_t = (k_{id} t^{\frac{1}{2}}) + C$	56
Equation 2.7	$\frac{C_e}{q_e} = \frac{1}{q_{max} b} + \frac{1}{q_{max}} C_e$	60
Equation 2.8	$q_e = K_f C_e^n$	61
Equation 2.9	$\text{log } q_e = \text{log } K_f + \frac{1}{n} \text{log } C_e$	61
Equation 3.1	$q_t = \frac{(C_o - C_t)V}{m}$	68
Equation 3.2	$q_e = \frac{(C_o - C_e)V}{m}$	69
Equation 4.1	$\text{LOD} = \frac{3SD}{m}$	86
Equation 4.2	$\text{LOQ} = \frac{10SD}{m}$	87
Equation 4.3	$R_L = \frac{1}{1 + bC_0}$	98

LIST OF ABBREVIATIONS

AC	-	activated carbon
ACC	-	American Chemistry Council
ACFs	-	activated carbon felts
ACGIH	-	American Conference of Governmental Industrial Hygienists
AC-H ₃ PO ₄	-	modified activated carbons
AFFF	-	aqueous film-forming foam
AOP	-	advanced oxidation processes
BET	-	Brunauer-Emmet-Teller
CDP	-	cyclodextrin polymers
DFT	-	density functional theory
diPAP	-	disubstituted polyfluoroalkyl phosphates
DOM	-	dissolved organic matter
DWTP	-	drinking water treatment plant
ECHA	-	European Chemicals Agency
EfOM	-	effluent organic matter
EI	-	electron ionization
EI+	-	electron-impact positive ionization mode
EPA	-	Environmental Protection Agency
F-53B	-	polyfluoroalkyl ether sulfonic acid
FASAs	-	perfluoroalkane sulfonamides
Fe/H-GAC	-	FeCl ₃ modified GAC
FeRB	-	iron-reducing bacteria
FO	-	forward osmosis
FOSA	-	perfluorooctane sulfonamide
FTAB	-	fluorotelomer sulfonamidopropyl betaine
FTAC	-	fluorotelomer acrylate

FTAL	-	fluorotelomer aldehyde
FTCA	-	fluorotelomer carboxylic acid
FTI	-	fluorotelomer iodide
FTMAC	-	fluorotelomer methacrylate
FTO	-	fluorotelomer olefin
FTOH	-	fluorotelomer alcohol
FTP	-	fluorotelomer-based polymer
FTS	-	fluorotelomer sulfonate
FTUAL	-	fluorotelomer unsaturated aldehyde
FTUCA	-	fluorotelomer unsaturated carboxylic acid
GAC	-	granular activated carbon
GC-APPI- HRMS	-	gas chromatography-atmospheric pressure photoionization- high resolution mass spectrometry
GC-MS	-	gas chromatography-mass spectrometry
IPD	-	intra-particle diffusion
ITRC	-	Interstate Technology Regulatory Council
LC-MS	-	liquid chromatography-mass spectrometry
LC-MS/MS	-	liquid chromatography/tandem mass spectrometry
LOD	-	limit of detection
LOQ	-	limit of quantitation
MCN	-	multi-walled carbon nanotube
MD	-	molecular dynamics
MO	-	Moringa Oleifera
monoPAP	-	monosubstituted polyfluoroalkyl phosphate
NaOH/NaCl	-	sodium hydroxide/sodium chloride
NF	-	nanofiltration
NIST	-	National Institute of Standard and Technology
NOM	-	natural organic matter
nZVI	-	nanoscale zero-valent iron

OECD	-	Organisation for Economic Co-operation and Development
OM	-	organic material
PACFs	-	polyacrylonitrile fiber-derived activated carbon fibers
PAP	-	polyfluoroalkyl phosphoric acid ester
PBSF	-	perfluorobutane sulfonyl fluoride
PEPE	-	polymeric perfluoropolyether
PFAAs	-	perfluoroalkyl acids
PFAI	-	perfluoroalkyl iodide
PFAS	-	per- and polyfluoroalkyl substances
PFBA	-	perfluorobutanoic acid
PFBS	-	perfluorobutanesulfonic acid
PFCA	-	perfluoroalkyl carboxylic acid
PFDA	-	perfluorodecanoic acid
PFEI	-	perfluoroethyl iodide
PFHpA	-	perfluoroheptanoic acid
PFHpS	-	perfluoroheptane sulfonic acid
PFHxA	-	perfluorohexanoic acid
PFHxI	-	perfluorohexyl iodide
PFHxS	-	perfluorohexanesulfonic acid
PFO	-	pseudo-first-order
PFOA	-	perfluorooctanoate acid
PFOS	-	perfluorooctane sulfonate
PFPeA	-	perfluoropentanoic acid
PFPEs	-	perfluoropolyethers
PFSA	-	perfluoroalkyl sulfonic acid
POPs	-	persistent organic pollutants
PP	-	polypropylene
ppt	-	parts per trillion

PSO	-	pseudo-first-order
RMSE	-	root-mean-square error
RO	-	reverse osmosis
ROS	-	highly reactive oxidant species
$S_2O_8^{2-}$	-	persulfate ions
SAFF	-	surface-active foam fractionation
SCG	-	spent coffee grounds
SD	-	standard deviation
SEM	-	scanning electron microscopy
SIM	-	selected ion monitoring
TFE	-	tetrafluoroethylene
TM	-	telomerization
USEPA	-	United State Environmental Protection Agency
VUV	-	vacuum ultraviolet
XRD	-	x-ray diffraction
XRF	-	x-ray fluorescence
γ -AlOOH	-	aluminium oxide hydroxide

LIST OF SYMBOLS

b	-	free energy of adsorption
$^{\circ}\text{C}$	-	degree Celcius
C	-	constant directly linked to the boundary layer thickness
C_0	-	initial concentration
C_e	-	equilibrium concentration of the FTO solution
Cl	-	chlorine
C_t	-	concentration of FTO in the solution at the time
F	-	fluorine
f_{oc}	-	organic carbon content
H	-	hydrogen
k_1/k_2	-	rate constant
K_{AW}	-	air-water partition coefficient
K_d	-	distribution coefficient
K_f	-	adsorption capacities (Freundlich)
K_{id}	-	interparticle diffusion constant
K_{OA}	-	octanol-air partition coefficient
K_{OC}	-	organic carbon-water coefficient
K_{OW}	-	octanol-water partition coefficient
m	-	dosage of adsorbents
m	-	slope
m/z	-	mass to charge ratio
n	-	Freundlich exponent
n	-	length of the alkyl chain in carbon atoms
q_e	-	equilibrium concentration
q_{max}	-	maximum sorption capacity
q/q_e	-	adsorption capacity
R	-	functional group linked to the chain
R^2	-	coefficient of determination
R_L	-	dimensionless separation factor

S_w	-	water solubility
t	-	time
V	-	volume of solution
x	-	number of non-fluorinated carbon atoms