

PERSISTENT ORGANIC POLLUTANTS (POPS): ENVIRONMENT PERSISTENCE AND BIOACCUMULATION POTENTIAL

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Abstract: Persistent organic pollutants (POPs) are widely environmental contaminants and represent a global problem. The environmental chemistry and ecotoxicology of persistent organic pollutants (POPs) represent every interesting domain of scientific research. Persistent organic pollutants toxicity in humans and wildlife is caused by their environment persistence and by their bioaccumulation potential in the tissues of animals and humans through the food chain.

This paper objective is to provide an overview about persistent organic pollutants, about their harmful effects on biota, and make some comments about: sample collection, extraction methods, analytical methods, POPs biomonitoring, POPs in atmospheric environment, POPs in the terrestrial environment and POPs in marine and freshwater environments.

Keywords: POPs · bioaccumulation · biota · biomonitoring · environment

1. INTRODUCTION

Environmental forensics appeared in the 1980s as a consequence of legislative frameworks for seek compensation with regard to contamination or injury due to damage to the environment. [1]

There are more than 100,000 existing chemicals on the market as an integral part of our modern life.

A number of these chemicals are substances of very high concern and they are persistent, bioaccumulative and toxic (PBT).

Chemicals categorized as PBT have the following properties:

- PBT are not break down easily in the environment;
- PBT accumulate in the tissues of organisms
- PBT are toxic.

Persistent organic pollutants (POPs) are a subcategory of the PBT category. POPs are compounds which are organic (natural or anthropogenic) in nature and resist to biological, chemical and photolytic degradation. [2]

POPs have been used for more than one century.

A substance can be classified as persistent if it has a half-life exceeding one of the following levels:

- soil or sediment: 180 days;
- surface water: 60 days;
- air: 2 days.

Single media calculations of half-life (Table 1) were undertaken in controlled laboratory environments and have been criticized by Gramatica and Papa. [3]

Table 1. Estimated half-lives of several POPs in different media

Compounds	Estimated half-life in air (days)	Estimated half-life in water (days)	Estimated half-life in soil (days)	Estimated half-life in sediment (days)
Aldrin	0.21	710	710	2300
Chlordane	2.3	710	710	2300
p,p'-DDT	7.1	230	710	2300
Dieldrin	2.3	710	710	2300
HCB	710	2300	2300	2300
PCB 3	7.1	230	710	710
PCB 209	2300	2300	2300	2300
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	7.1	23	710	2300
OCDF	23	230	2300	2300
Toxaphene	7.1	2300	2300	2300

POPs, once released to the environment, have long half-lives persisting in the environment (soils, sediments, air, or biota) for extended periods.

Combining POPs stability and inclination to exist in the gaseous phase means that they are subject for long-range transportation and that they accumulate in food chains.

The physicochemical properties described in the previous section begin to explain why POPs behave the way they do.

The main environmental processes that control the persistence of a compound are:

- Transport: volatilization, dilution and advection;
- Partitioning: sorption, uptake by organisms;
- Degradation: biodegradation (aerobic, anaerobic, and metabolism) and abiotic degradation (hydrolysis, photolysis, oxidation and reduction).

POPs in the environment are not present in just one phase, there is a constant dynamic equilibrium whereby POPs

are shifting through the different phases.

POP proportion in each phase is dependent upon the chemicals physicochemical parameters. The main processes are presented in Figure 1.

In soils, POPs tend to bind to organic matter and to be fairly localized contaminants as transportation in ground water is minimal.

In aquatic medium, POPs tend to bind strongly to solid particles and therefore can be only detected in low concentrations in dissolved phase.

These compounds with semi-volatile character can be found in the gaseous phase in association with atmospheric particles or distributed between these two phases.

The air is the main transport media for the global distribution of POPs.

Once released into the environment, they travel in by evaporation, condensation and air transportation.

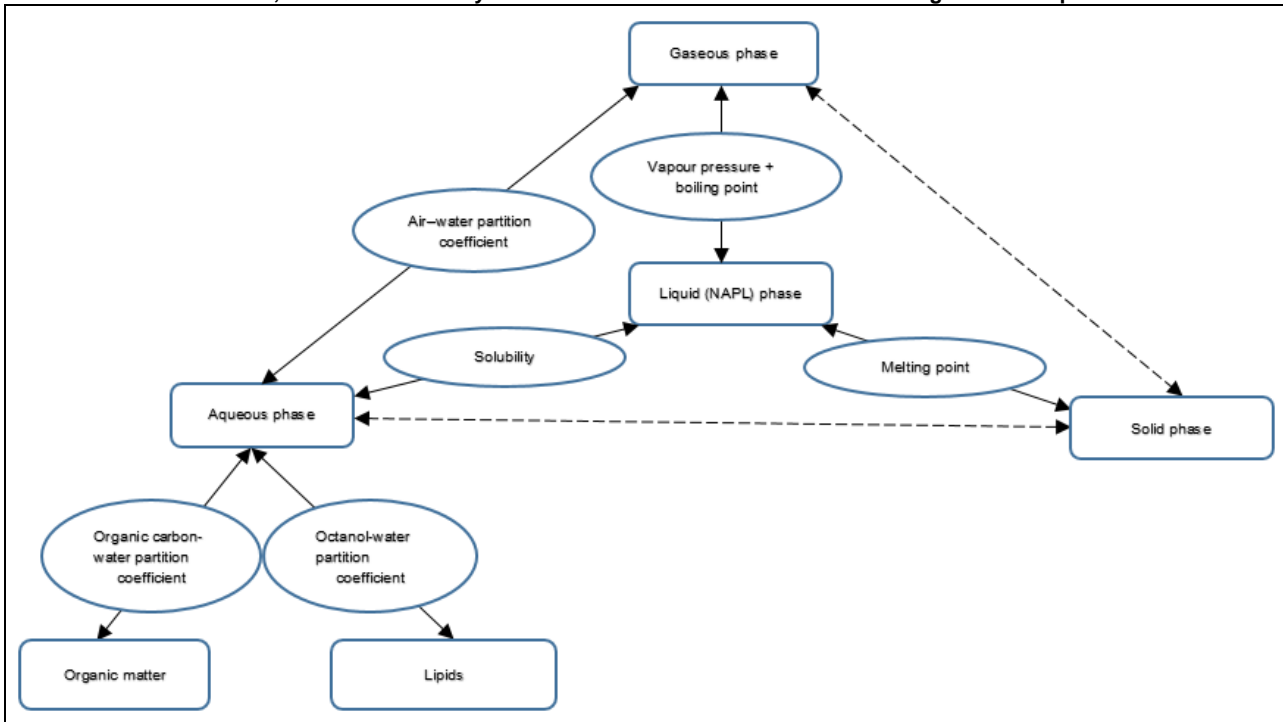


Figure 1. The influence of dynamic equilibria scheme of the POPs proportion in each phase

POPs are typically hydrophobic and lipophilic, so once they enter into a biological system, they are not easily excreted. In biological systems, POPs tend to partition into lipids which causes POPs accumulation into organs and fat tissue.

Over time POPs accumulate in the living tissue of an organism, a process called bioaccumulation.

POPs biomagnification is the increase in POPs concentration when the contaminated materials (like plants and animals) pass up the trophic levels of the food chain.

POPs bioaccumulation and magnification in the food chain affects us at the end, so it is very important that POPs presence and levels are highly analysed for researchers.

2. SAMPLE COLLECTION

Sample collection information data must provide a commentary of all activities that take place, potentially including the following:

- Date and times on location
- Weather conditions
- Personnel present
- Site conditions
- Site activities
- Simplified site schematics
- Relevant conversations
- Sample identification numbers
- Sample locations and collection methods
- Times of sample collection
- Notes regarding the description of samples taken.

The containers normally used for standard environmental sampling routines are coolers.

However, most coolers used for transport have a large, loose opening that cannot be locked, thus potentially tampered with.

For an additional degree of security, coolers can be sourced with lockable clasps.

Security seal or "legal tape" is standard tape used to provide a seal on individual sample vessels and carriage equipment.

There are numerous technologies that can provide additional security to standard security seals, strongly advised for legal sampling events:

- Frangible tape
- Leaves indicative residue
- Printed serial number
- Barcode
- Shrink band

Temperature control is a very important factor for numerous environmental samples.

If the samples are not maintained at a specified temperature this can invalidate samples, due to potential loss of contaminants by enhanced degradation and volatilization.

The maintaining of a specified temperature is often managed with ice, ice packs, or ice-blocks.

Samples should be cooled, but they should not be frozen so the target maintaining temperature for numerous samples is 4°C.

Achieving and maintaining a good temperature control is only worthwhile if it can be effectively demonstrated.

Effective demonstration removes doubt and provides a very strong line of evidence for sample (temperature) integrity.

Modern temperature data loggers are miniature sealed devices that can be transported amongst samples.

Receiving the samples from the investigator normally occurs in the analytical laboratory.

At this moment, the sample overpack containment must be inspected for integrity both by the investigator and the laboratory receiver.

Often is used a photographic evidence at this point to proving the sample integrity. Photographic documentation at this point provides certain evidence that sample integrity was maintained. After photographic evidence, the containment seals must then be broken and the sample list must be checked off against the physical sample inventory.

Seals on samples must be inspected for evidence of tampering, but these seals must remain intact at this point.

Sample collection and management for environmental forensic investigations begins a long time before field activities.

In fact, most of the actual field activities are the same as nonforensic investigations.

The quality systems around which the investigation

is built actually makes a field event robust and defensible.

3. EXTRACTION METHODS

Over 100,000 chemicals are currently in use or present in consumer products with over 30,000 considered to be in wide commercial use.[4]

Most of these compounds are persistent, toxic and bioaccumulative and they are detected in all types of environmental matrices. The Stockholm Convention on persistent organic pollutants (POPs) targets only 21 compounds or compound groups including the original 12 as listed in Table 2: 9 organochlorine (OC) pesticides,

polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) [5].

A very important step in the field of analytical chemistry is to use the proper extraction, preparation and instrumental techniques. The purpose is that the accuracy and uncertainty of the technique is acceptable to meet the required data quality objectives. The final idea is that the analytical method used is fit for the purpose for which it was intended.

Table 2. List of compounds under the Stockholm Convention

Category	Compounds
Pesticides	Aldrin Chlordane Dieldrin DDT Endrin Heptachlor Hexachlorobenzene (HCB) Mirex Toxaphene
Industrial chemicals	PCBs
Unintentional production	PCDDs and PCDFs PCBs HCB
Added – May 2009	Chlordecone α-hexachlorocyclohexane β-hexachlorocyclohexane Hexabromobiphenyl Hexabromodiphenyl ether and heptabromodiphenylether Lindane (γ-hexachlorocyclohexane) Pentachlorobenzene PFOS, its salts and perfluorooctanesulfonyl fluoride Tetrabromodiphenyl ether and pentabromodiphenylether
Compounds under review, nominated for addition – October 2009	SCCPs Endosulfan HBCD

Different degrees of sensitivity or selectivity may be required and as a result different methods could be used in order to answer each one of these questions. Cost and speed

can also be important considerations.

Table 3 presents the LD50 concentrations for the rat by increasing toxicity from top to bottom.

Table 3. Relative Toxicity of Various POPs

Compounds	LD50 Oral – Rat (mg/kg)
HCB	10,000
α-BHC	>2000
Total PCB (Aroclor)	1000
DDE	880
2,4-D	370
3,4,5-T	300
PFOS	250
Mirex	235
Chlordane	200
DDT	87
Lindane (γ-BHC)	76
Toxaphene (total)	50
Aldrin	39
Dieldrin	38
Pentachlorophenol	27
Endosulfan	18
Endrin	3
PCN 67	1
PCB-126	0.2
2,3,7,8-TCDD	0.02

Table 4 summarizes possible methods that can be used to analyze some of the compounds presented in Table 2 and Table 3.

Table 4. Analytical Schemes for some POPs examples

Compounds	Analytical Method
Chlorobenzene	GC-ECD
PCBs (total)	GC-ECD
OC pesticides	GC-ECD
PCBs – Congener	GC-ECD
	GC/MS
PAHs	GC/MS
BDEs	GC/MS
	GC/HRMS
PCNs	GC-ECD
	GC/NCI MS
PCBs (dioxin-like)	GC/MS
	GC/HRMS
Dioxins/furans	GC/HRMS
	GC/MS/MS

Generally, when the toxicity of the compound increase, the required method become more complex, requiring larger sample sizes, more comprehensive cleanup schemes, smaller final extract volumes, more sensitive and selective instruments, longer analysis times and greater costs.

Analytical methods used for POPs follow the same basic analytical scheme:

- extraction of analytes from matrix;
- separation of analytes from interfering matrix coextractables;
- analysis of cleaned extract using chromatographic separation followed by instrumental detection.

Selecting the correct analytical approach is critical in order to obtain the best quality data possible.

Sample extraction is a critical step that is required to separate the analytes of interest from the bulk matrix so that they can be cleaned by chromatographic separation, concentration and instrumental analysis.

Internal standards are added prior to extraction and are typically added to the sample for quality control.

Accuracy and precision are strongly dependent on the number of internal standards and type of calibration used.

Aqueous samples and other liquid samples like biological fluids have classically been extracted using liquid/liquid extraction.

If samples for persistent organic pollutants analysis contain particles, they can be filtered to isolate the particles.

If the analytes of interest are present at significant levels on the particles (e.g., dioxins, PCBs, BDEs (brominated diphenylethers)), they can be extracted using solid extraction procedures.

Aqueous samples can also be extracted using solid-phase extraction (SPE), a technique that uses a stationary phase, in an extraction cartridge or disc to extract nonpolar analytes like dioxins, PCBs from polar liquids or divinylbenzene (DVB) for more polar compounds.

Extraction of samples by SPE also allows for the particles to be trapped on top of the extraction disc or bed.

Other procedures can also be used to extract aqueous samples, including sorptive stir-bar extraction (SBSE) with thermal desorption directly into the gas chromatograph (GC) [6] or hollow fiber liquid-phase microextraction (HF-LPME) [7] where small amounts of solvent are trapped in the pores of the hollow fiber extract concentrating the analytes of interest.

Solid-phase microextraction is a technique where a fiber is coated with a specific stationary phase.

Solid matrices (e.g., soil/sediment, biota, or vegetation) have classically been extracted using Soxhlet extraction.

Pressurized liquid extraction (PLE – also known as accelerated solvent extraction (ASE)) [8], microwave-assisted extraction (MAE) [9] and sonication can also be used.

Wet samples (sediments, biota, and vegetation) can be Soxhlet extracted with a device which separates water from

less dense nonpolar solvent.

Supercritical fluid extraction [10, 11] is a procedure that uses supercritical carbon dioxide and requires no solvent for extraction and only a very small amount of solvent to trap the analytes or elute them from the carbon or trapping material.

Usually, sample extracts must be concentrated prior to cleanup.

There are a variety of sample concentration procedures that can be used, including nitrogen or gas blow down, rotary evaporation, Kuderna Danish concentration, or automated evaporative concentration.

4. ANALYTICAL METHODS

Most extraction procedures for persistent organic pollutants are quantitative and able to extract a variety of organic compounds as well as other organic matrix coextractables.

The detection of analytes can be accomplished using a number of different instruments.

When selecting the instrument and instrumental analytical procedures, sensitivity and selectivity are the main considerations.

Nonselective detectors, such as flame ionization detection (FID) and electron capture detector (ECD), were used extensively prior to 1990, but are now used mainly for screening.

Spectacular advances in mass spectrometry have given rise during the past two decades to commercially available instruments, that are highly automated, simple to operate and less expensive to acquire.

Mass spectrometry is at this moment the most selective and sensitive detector for most of environmental forensics applications and also offers the key advantage of using mass-labeled internal standards, which can significantly increase accuracy and precision.

Mass spectrometry gives accurate and precise results and it is critical in regulatory, forensic and litigation applications.

A laboratory must have a comprehensive quality assurance/quality control program that includes accreditation for as many analytes as practicable in order to ensure the best possible results are produced.

Accreditation ensures that laboratories are following proper procedures and participating in performance evaluation studies to assess data quality.

The first step in the accreditation process is full method validation and initial performance evaluation.

Critical steps in the production of a rugged analytical method that produces reproducible results with the required accuracy and uncertainty are method development and validation.

Key method attributes are: sensitivity (detection limits), selectivity, accuracy, and uncertainty (precision) and are important considerations when selecting an analytical method.

There are three types of analytical methods:

- Reference method
- Modified method
- In-house method

Calibration is one of the most important steps that determines the data quality of a method.

It defines the accuracy and precision of the method. The various types of calibration are detailed below. The instrument must be standardized to ensure it is analyzing the required analyte.

For mass spectrometers, this involves calibration of the mass scale using calibration compounds. Mass calibration is critical for high-resolution mass spectrometers which must be continuously calibrated to ensure mass accuracy.

5. POPS BIOMONITORING

Biomonitoring has become an indispensable tool for studying occupational and environmental exposure to chemicals, including persistent organic pollutants (POPs) [12].

Using of biomonitoring data in a forensic context is the reason to understand the potential exposures to specific sources or to identify historical elevations in exposure.

Biomonitoring requires consideration of many factors like:

- differential toxicokinetic properties of POPs;
- issues in analytical determination and measurement of POPs concentrations in human biological matrices;
- typical patterns of biomonitoring results in populations without unusual exposure;
- efficacy of potential and demonstrated routes of exposure.

Persistent organic pollutants have been the object of biomonitoring studies for more than 60 years.

Biomonitoring has become the primary tool for human exposure characterization for persistent organic pollutants.

POPs have some physical and chemical characteristics that lead their persistence in the environment and into biological systems, with limited metabolism, slow elimination, and resulting bioaccumulation.

The measured levels and patterns results obtained of POPs in human tissues requires consideration of the details of the toxicokinetics of the compounds as well as consideration of exposure patterns several decades.

The utility of biomonitoring for exposure assessment for POPs are related with their fundamental physical and chemical characteristics, their extreme hydrophobicity (and resulting lipophilicity) and resistance to biological or chemical degradation.

These fundamental characteristics influence the resulting biomarker concentrations reflecting these processes and the absorption, distribution, metabolism and elimination of POPs.

It is important to continue to test and develop more sensitive analytical methods for environmental chemicals:

- to determine the normal human chemicals levels shown to be toxic to certain animals;
- to continue monitoring chemical levels that are decreasing in populations around the world;
- to provide better analytical coefficient of variations of chemicals;
- to provide a lower analytical coefficient of variations translates directly into higher statistical power in epidemiological studies.

A widely exposure characterization tool in studies of populations with potentially elevated exposures to POPs (both in an environmental and an occupational context) has been biomonitoring as well as in studies of general population groups without known elevated exposures in order to explore possible exposure-response relationships.

Exposure events occurring many years in the past may be detectable through the use of biomonitoring because of the extreme persistence of these compounds.

It is a known fact that biomonitoring data can be used to evaluate exposure assessments based on measurements in environmental media or on judgments

regarding exposure potential.

These data can also provide insight into the relative importance of various exposure pathways.

Biomonitoring may also provide insight into the effectiveness of exposure interdiction strategies.

6. POPS IN THE ATMOSPHERIC ENVIRONMENT

The atmospheric transport and fate of persistent organic pollutants (POPs) have been the subject of intensive research and regulatory actions for many years.

a) Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are persistent organic pollutants found in all environmental compartments, including atmosphere, water, sediments, and soils.

In nature, PAHs are produced:

- by diagenesis of organic matter at low temperatures;
- during formation of petroleum and coal;
- by incomplete or insufficient combustion at moderate to high temperatures (pyrolysis);
- by biosynthesis.

PAHs are produced by a variety of sources, which can be divided into several major categories: natural, domestic, mobile, industrial, and agricultural sources [13].

Globally, the major sources of PAH emissions are biofuel (including straw, firewood and animal dung), wildfires, and consumer product usage, which includes PAHs emitted during the use of personal care products, household products, automotive after-market products, adhesives and sealants, coatings, and other regulated products [14].

PAHs are subject to several atmospheric processes that contribute to their residence times in the air: partitioning between gas and particle phases, wet and dry particle deposition, diffusive exchange between water bodies, photolysis and chemical reactions with atmospheric oxidants.

b) Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) are persistent semivolatile organic compounds that have been extensively used since 1930 for a variety of industrial uses. During the period of their production and use, direct emission to the atmosphere was the major air pollution source and pathway and soil was a primary depository of PCBs. PCBs in the atmosphere exist in two compartments: gas phase and particle phase; this partitioning affects their transport and reactivity in the atmosphere.

c) Polybrominated compounds

There is a wide variety of brominated compounds that are commercially manufactured, the majority of which are used as flame retardants, fumigants, and antifungals [15].

d) They are added to a wide variety of plastics, foams, polymers, and textiles in furnishings, electronics, building materials, and vehicles. Some of them are used as additives and many brominated compounds are added to plastics and foams at concentrations of up to 30% by weight and are not chemically bound to the plastic matrix, but some of them are instead "reactive" and can be covalently bound to the plastic matrix [16].

e) Perfluorinated compounds

Polyfluorinated compounds and perfluorinated alkyl compounds (PFCs) are a highly valued group of anthropogenic chemicals that represent a large global commercial market. PFCs are characterized by a saturated fluorinated alkyl chain on one end and are generally capped on the other by a polar nonfluorinated moiety. The identification of PFCs in remote Arctic and southern hemisphere environments highlights the significance of atmospheric transport of these anthropogenic inputs [17]. The high stability of PFCs is allowed by the strong carbon-fluorine bonds and determine the persistence of compounds.

e) Polychlorinated dibenzo-p-dioxins and dibenzofurans

Polychlorinated dibenzo-p-dioxins (PCDDs or "dioxins") and polychlorinated dibenzofurans (PCDFs or "furans") are not created intentionally, but are produced by a number of human activities like chemical manufacturing and incomplete combustion or by natural processes like volcanoes, forest fires and geologic processes. Dioxins and furans are the most

studied chemicals in terms of their formation processes, environmental occurrence and toxicity.

7. POPS IN THE TERRESTRIAL ENVIRONMENT

Terrestrial environment means land-based areas and the biota that live there and includes man-made and natural surfaces, subsurface features and the interfaces with the atmosphere and the oceans.

Persistent organic pollutants (POPs) come into the terrestrial environment by use and disposal; this includes intentional discharges and unintentional spillages and leaks.

POPs are relatively immobile and do not readily degrade. This is the reason that after releases to the environment, they can remain in soils and sediments in localized areas at high concentrations.

a) *Soils and sediments*

Persistent organic pollutants can enter the soil through intentional discharges, unintentional spillages and leaks and aerial deposition.

Once they have been released to the environment, POPs can be carried out all over the globe by atmospheric transport that can occur through the vapor pathway, windblown dust and particulate matter which has been contaminated with POPs.

Global distillation and cold condensation describe how POPs volatilize from warm source areas, undergo long-range atmospheric transport and subsequently condense onto surfaces, such as soil, vegetation, or snow, at low temperatures, effectively accumulating in the polar regions.

b) *Herbage*

In theory, POPs can enter vegetation through two main media, air and soil; however, the exact pathways are not fully understood or quantified.

There are many variations, such as wind speed, temperature, the reactive surface of the leaf, and the permeability of cuticle wax, which can all affect the intake of POPs through air. For most vegetation, the uptake from the soil is considered negligible.

A summary of potential pathways for POPs to enter vegetation includes: contamination of shoots and cuticles from aerial deposition of wet and dry particulates, uptake through roots and xylem transport to other parts of the plant, uptake of airborne vapors through stomata and adsorption and absorption onto roots and tubers in the ground and parts of the plant in close proximity to the ground. [18]

The main properties of persistent organic pollutants are: generally highly lipophilic, low volatility and low solubility, therefore, the transfer of POPs from the soil to vegetation would be expected to be relatively low but real.

c) *Wildlife*

The main ways that persistent organic pollutants enter animals is ingestion of contaminated food.

Polychlorinated biphenyls (PCBs) and other persistent organic pollutants present in fish strongly influence the profile in fish eating birds present in the food chain. The studies result shows different concentrations and profiles found in terrestrial predatory birds feeding on small mammals in comparison to predatory birds feeding on small passerine birds.

d) *Humans*

POPs can enter humans through three main pathways: ingestion, inhalation, and dermal contact (through the skin).

The vast majority of people will only be exposed to background concentrations of POPs, which will occur throughout their lifetime. The majority of this exposure will occur through ingestion of contaminated foods [19].

8. POPS IN MARINE AND FRESHWATER ENVIRONMENTS

Persistent organic pollutants (POPs) are organic compounds of natural or anthropogenic origin that resist photolytic, chemical, and biological degradation.

Examples include polychlorinated biphenyls (PCBs), dioxins and furans, many pesticides and certain metals, particularly mercury. Although many countries have banned or severely restricted the production and use of POPs in recent

decades, these substances are pervasive and can be found in remote environments around the world [20, 21].

It is a fact well known that POPs have the ability to migrate long distances from their original source.

Inputs of POPs from the atmosphere and surface waters, and releases from sediments and removal pathways such as volatilization and sedimentation may explain, in part, why countries that banned the use of certain POPs are experiencing less dramatic declines in environmental concentrations nearly a decade later [22].

POPs are hydrophobic and lipophilic chemicals. In aquatic environments and soils they partition strongly to organic matter and avoid the aqueous phase. Persistent organic pollutants distribute between particles, colloids and the water phase.

When POPs sorb to particles and colloids, the freely dissolved concentrations decrease and, thus, also the bioavailability to aquatic organisms.

On the other hand, the sorption of POPs to colloids can enhance environmental transport due to the higher mobility of small colloids compared to larger particles. Colloids can also facilitate the transport of POPs over the thin stagnant aqueous films (i.e., diffusive boundary layers) that are present at the interface between water and sediment or on passive samplers.

The extent of sorption to particles and colloids and the distribution between different phases in the aquatic environment has a large impact on POP migration in the environment and fate processes, such as sedimentation, bioavailability, and degradation. [23]

a) *Polyfluoroalkyl compounds*

The occurrence and fate of fluorinated compounds in the aquatic environment is recognized as an important emerging contaminant issue. Since the 1990s, knowledge about variety, worldwide distribution, environmental fate and transport pathways of polyfluoroalkyl compounds has advanced substantially concurrent with improving analytical methods.

PFASs are persistent and bioaccumulative and have been detected in various environmental matrices, including freshwater [24] and marine waters [25, 26].

b) *Pharmaceuticals and personal care products*

Pharmaceuticals and personal care products (PPCPs) are a large class of thousands of chemical substances, including prescription and non-prescription over-the-counter drugs, veterinary drugs, fragrances, sunscreens, detergents and cosmetics. Among this category of compounds, some are capable of disrupting the endocrine system of animals, including fish, wildlife, and humans; these substances are termed endocrine disrupting chemicals (EDCs) and are the most dangerous ones.

c) *Engineered nanomaterials*

Engineered nanomaterials (ENMs) enter the aquatic environment through controlled and uncontrolled atmospheric emissions and solid or liquid waste streams from several industrial sectors:

- semiconductors;
- memory and storage technologies;
- display, optical, and photonic technologies;
- energy;
- biotechnology;
- paints and pigments;
- pharmaceuticals;
- textiles;
- health care and personal care product manufacturers.

d) *Flame retardant compounds*

Flame retardants are chemicals used in thermoplastics, thermosets, textiles, and coatings to inhibit flammability or resist the spread of fire. There are more than 175 different types of flame retardants, which are generally divided into four classes that include the halogenated organic (usually brominated or chlorinated), phosphorus-

containing, nitrogen-containing, and inorganic flame retardants.

e) This is the most significant class of substances and include five major types-brominated bisphenols, diphenyl ethers, cyclododecanes, phenols, and phthalic acid derivatives. [27]. *Polycyclic aromatic hydrocarbons*

PAHs are weakly volatile, have a low solubility and are chemically inactive but bond to particulate matter. In surface water, PAHs volatilize, photolyze, oxidize, biodegrade, bind to suspended particles or sediments or accumulate in aquatic organisms (lowest trophic level). Polycyclic aromatic

hydrocarbons are widely environmental contaminants.

Although they can be formed naturally, their main source is anthropogenic emissions and the highest concentrations of PAH are generally found around urban centers. Concentrations of PAHs in the aquatic environment are generally highest in sediment, intermediate in biota and lowest in the water column.

CONCLUSION

The environmental chemistry and ecotoxicology of persistent organic pollutants is a very important area of scientific enquiry. This pollution impact of POPs is a fascinating, active, multidisciplinary and energetic domain of science at this moment.

Proper removal techniques of persistent organic pollutants from the environment are still unclear, due to fear that more toxic byproducts may result from uninvestigated degradation techniques. Current efforts are more focused on banning the use and production of POPs worldwide rather than removal of POPs. Active areas of current and future research for the next few years may be:

- improvements in the source inventories and refinements in pathways and exposure analyses;
- more detailed, sophisticated and refined studies on the air surface exchange of POPs;
- global scale analysis and a more comprehensive geographical coverage of chemical concentration and flux data;
- increasing the sophistication of the development of physicochemical property-based models;
- studies on the form, bioavailability, fixing and remediation of POPs in soils, sediments and groundwater;
- studies of POPs effects on humans and wildlife, including biodegradation, transformation and toxicity mechanisms;
- studies of 'newer' and perhaps more polar persistent compounds classes of POPs;
- analytical methods improvement to identify and quantify new POPs, notably metabolites, stereoisomers and more polar POPs.

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