Environmental Chemistry

Part 5 Biospheric chemistry

5.1 Bioaccumulation of Pollutants

Concept and Importance of Bioaccumulation

- It is a process by which persistent environmental pollution leads to the uptake and accumulation of one or more contaminants, including persistent endocrine disruptors, by organisms in an ecosystem.
- The amount of a pollutant available for exposure depends on its persistence and the potential for its bioaccumulation.

Basic Factors Affecting Bioaccumulation

- Water, soil, air, plants, and any of their combinations can be an ecosystem for chemical bioaccumulation.
- Bioaccumulants tend to be persistent, stable, and lipophilic environmental pollutants.
- Chemicals tending to move freely within an organism's body are less likely to be accumulated by organisms.

Uptake of Bioaccumulants

- The uptake of many bioaccumulants by organisms is typically initiated by passive transport, as chemical molecules tend to move from high to low concentration.
- This first step is affected by the bioaccumulant's lipophilicity and water solubility.
- Some chemicals also have a high affinity for binding with proteins or the ability to dissolve in fats, thus prolonging the storage of these substances inside an organism.

Bioactivity of Pollutants

- Accumulation of an endocrine disruptor inside an organism will pose threat of interference only if the contaminant is in a form active for binding to hormonal sites.
- Bioaccumulants having the affinity to bind to plasma proteins are less biologically available or active for hormonal disruption.
- Many environmental endocrine disruptors are more bioactive, compared to endogenous steroid hormones.

Mobility of Pollutants

- Persistent endocrine disruptors can reach remote regions via atmospheric, oceanic, or terrestrial transport.
- Animal migration (biotransport) is the fourth mode of long-range transport of bioaccumulants.
- Biotransport appears to be much more significant than the other three modes, in part because the contaminant loads are more localized and in part because the contaminants are more biologically active.

Biotransport of Pollutants

- Salmon, seabirds, whales, migrating birds, and eels are some of the animals capable of transporting pollutants from one region to another; in some cases, even to such remote regions as the Arctic.
- The amounts of some persistent organic pollutants (POPs) transported by migratory animals may be in a similar order of magnitude as those by other modes of long-range transports.

Breakdown of Pollutants

- The biological breakdown of chemicals is called metabolism; this ability varies among individual species.
- Some chemicals are highly fat-soluble but are easily metabolized; these chemicals do not accumulate in organisms.
- Thus, biological breakdown is one of the factors leading to one of the two specific consequences of chemical bioaccumulation: bio*concentration* or bio*magnification*.

Metabolites of Pollutants

- Metabolites of some persistent organic pollutants are more bioactive as endocrine disruptors.
- Some metabolites, such as DDE, have their own unique active roles as an endocrine disruptor that their parents do not have.
- PCBs are other examples known to have metabolites with hormonal activities more potent and, in some instances, different than those of their parents.

Other Factors Affecting Bioactivity

- Not all metabolites of endocrine disruptors are more biologically active or available; some metabolites are less active than their parent compounds.
- Some endocrine disruptors can disable the osmoregulatory system of a bioaccumulating organism (e.g., a young salmon), by interfering with the estrogenic effects in this organism; it is this osmoregulatory system that makes endocrine disruptors more bioactive.

BAF, BCF, BMF

- Bioaccumulation Factor (BAF) is the ratio of a test chemical's concentration in a test organism's tissues to that in the surrounding medium, when all potential uptake mechanisms are included.
- Bioconcentration Factor (BCF) is a specific case of BAF, when the uptake is only from the surrounding medium.
- Biomagnification Factor (BMF) is the ratio of a test chemical's concentration in the tissues of an organism, to that in the organism's prey.

Methods for Baseline BAF

- Four (4) methods are available for use to calculate baseline bioaccumulation factor (BAF) for organic chemicals, and two (2) for inorganic chemicals.
- These methods include the use of field studies, and those based on multiplication of a measured bioconcentration factor by a food-chain multiplier.
- The term *baseline BAF* implies that the factor is measured under some standardized conditions (for ease of comparison).

Numerical Criteria for Bioaccumulation Potential

- In the USA, chemicals are considered bioaccumulative if they have a degradation half-life > 30 days; *or*
- If they have a bioconcentration factor greater than 1,000; *or*
- If their log K_{ow} is greater than 4.2.
- These values are lower (i.e., more health conservative) than those set forth by Canada and many other Western countries.

Bioconcentration Factor (I)

- Many bioconcentration factor (BCF) assessments are based on aquatic measurements because fish provides a rich lipophilic microenvironment for bioaccumulation.
- BCF is typically measured as the ratio of the concentration of a chemical in a test organism to the chemical's concentration in the surrounding medium.
- For many lipophilic chemicals, BCFs can be calculated using the regression equation: $\log BCF = -2.3 + 0.76 \times (\log K_{ow})$.

Bioconcentration Factor (II)

- The bioconcentration factor (BCF) can be calculated from K_{ow}, through use of the log-log QSAR relationship.
- U.S. EPA has been using the BCFWIN software developed by SRC for measuring the BCFs for many chemicals.
- SRC's BCFWIN program is designed to estimate the BCF using the test chemical's K_{ow}, based on the log-log fit generalized from some 694 chemicals.

Bioconcentration Factor (III)

- For a bioconcentration factor (BCF) to be estimated from a site-specific study, three (3) conditions should be met.
- For a BCF to be estimated from a laboratory study, five (5) conditions should be met.
- These conditions include: sufficient duration for observation; a subthreshold test levels; and the use of test guidelines acceptable to the regulatory authorities.

Kinetics Models for Bioaccumulation

- PB-PK simulation is the more complex of the two types of kinetics models.
- This complex type allows the incorporation of more detailed inputs on biological mechanisms into the bioaccumulation process. It requires far more input data than typically available.
- Kinetics models of the simple form each typically involve a single compartment for the uptake of chemicals by a test organism.

Effects and Incidences

- The effects of chemical bioaccumulation towards endocrine disruption are real; they can be better appreciated with some understanding of a chemical's persistence.
- As a real incidence, unrestricted uses of PCBs were banned in the USA in the early 1970s, after mounting evidence of its bioaccumulation in the environment was reported.
- Arctic explorers also experienced Vitamin A intoxication following meals of polar bear liver, where the compound is concentrated.