Risk assessment

PREDICTING PERSISTENCE AND BIOACCUMULATION OF CHEMICALS

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Introduction

Chemicals control seems to rely most heavily on T - the toxicity of a chemical, possibly due to experiences of rather toxic compounds being produced and marketed. However, the chemicals should also be assessed in relation to their persistency (P) and bioaccumulative (B) potency. This is related to the expected consequences of finding the chemical(s) in the environment. Historically, chemicals have been regulated in retrospect to their introduction on the market, but their occurrence in human tissues or body fluids, or if persistently present in other parts of the environment, have basically never been enough to limit the use of, or to ban, a chemical. Accordingly it has been important to prioritize the generation of knowledge of the toxicology of the compound to decide on control measures. Of course providing sufficient data on T is prioritized for the assessment of chemicals designed to possess a certain type of toxicity, like pharmaceuticals and pesticides. In contrast, additives applied to modify polymers, rubber, paper etcetera have often been on the market for quite some time before being questioned from an environmental or human health perspective. None of the PBT criteria have then really played a role to predict the properties of the chemical and accordingly have not been used for prioritization of their control. Persistency and bioaccumulation are strongly related to low chemical reactivity and to physico-chemical characteristics of a substance. We propose herein the possibility to use chemical reactivity as a novel prioritization tool in chemicals control.

Hypothesis

Our approach is to apply experimental reactivity data for chemical species to assess the reactivity (or stability) of a compound in the abiotic environment and in biota. By applying the reactivity of the compound it should be possible to model the persistency, and the bioaccumulative potency, a compound may exert. This is a tool that has not previously been tested for assessing chemicals.

Discussion

Persistency is a concept with numerous definitions, sometimes mixed with the definition of persistent organic pollutants (POPs) as in the case of the Stockholm convention stating "'*chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in fatty tissues of living organisms and are toxic to humans and wildlife.*" [1]. Still the general conceptual view on persistency is linked to high hydrophobicity and chemical stability of a compound. Even though physicochemical parameters are often quite easy to measure the chemical stability is not. A range of tests including ready biodegradability test (RBT), hydrolysis and radical reactivity are used aiming to describe reactivity's of chemicals [2]. Applying the RBT includes a biological method for degradation of chemicals but not of their transformations, i.e. formation of stable metabolites as 4,4'-DDE being formed from 4,4'-DDT. Hence the predictive power of RBTs of chemicals is particularly questionable to apply for assessing the stability of chemicals. The RBT once developed for degradation studies of detergents is not easily applied for highly lipophilic compounds, something that has been shown over and over again. Also the OECD hydrolysis test is of limited value as performed today [3]. The radical reactivity of chemicals in the environment is based on modelling allowing assessment of a large number of chemicals undergoing radical initiated reactions [4].

Persistency is hitherto mainly discussed along the lines of environmental partitioning and the modelling there from. Still, which has been pointed out, the lack of chemical reactivity data is a major drawback for assessing the fate of chemicals, a data gap that must be filled. The chemical reactivity has a strong influence on persistency, similar to that of the chemico-physical characteristics of the compound. A highly stable chemical, only undergoing very slow transformations under abiotic conditions, is available for partitioning in the environment

according to its physico-chemical constants. This means that it does not matter if the compound is very lipophilic if it is easily transformed in any of the environmental compartments (air, water, soil or sediment). Persistency may thus be described as outlined in Figure 1. This presentation of persistency plus a workable definition to make "persistency" operational was recently put forward by Green and Bergman [5]. The definition being "*The persistence of a chemical is its longevity in the integrated background environment as estimated from its chemical and physicochemical properties within a defined model of the environment*".
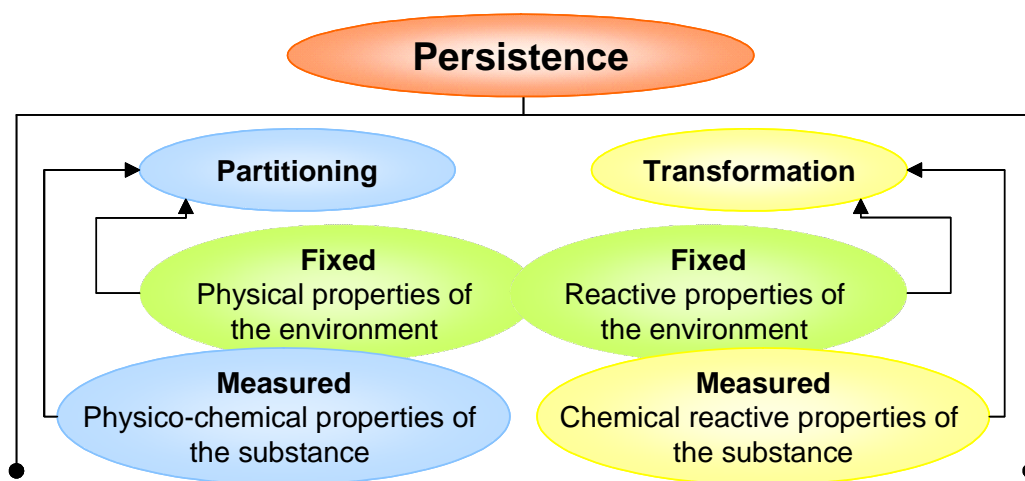

Figure 1. Principal sketch of persistence suggested by Green and Bergman [5].

The established approach takes up four separate media (air, water, soil, sediment) and the delineated transformation systems are: in air – vapour phase hydroxyl radical reaction; in water – aerobic microbial degradation, reaction with water and photolysis in water; in soil – aerobic microbial degradation and reaction with water; in sediment – anaerobic microbial degradation. The poor quality compartmental transformation rates this provides may be either because this level of delineation is insufficient (or data is not available for each type of degradation), or because the methods for measuring these degradation rates are not appropriate for giving representative values for the targeted environmental media. Alternatively, it may indicate that the complexity of the environmental system is too great to be able to simplify to a sufficiently manageable level without introducing impractical levels of error.

In our proposed system, we attempt to encompass all possible reactions in each of the media. These reactions are categorised according to their class of reaction, irrespective of how they are carried out. We consider five classes of reaction to cover all possible reactions: hse-reactivity (hydrolysis/substitution/elimination), oxidations, reductions, direct photolyses and reaction with radicals. We consider each class in each media, although some combinations will be negligible (e.g. photolyses in sediment, reductions in the atmosphere). For the purpose of providing a framework for assessing the persistence of a wide array of chemicals, the environment must be fixed with regard to both its distribution parameters and its reactivity. Compartmental transformation rates for the chemical can be derived from multiplication of a 1 x 5 matrix containing the substance reactivity constants by the environmental matrix (Figure 2). Thus, for example, whereas a chemical may have a high reactivity towards photolysis, the reactive power of the sediment compartment for photolytic reactions ($\varepsilon_{h\gamma\text{-sed}}$) should be negligible ($\sim 0$) and hence the photolysis of the chemical in the sediment will provide a negligible contribution to its total reactivity in the sediment compartment.

The persistence of any chemical in the defined, standard environment can then be calculated from its physicochemical properties – K_{ow}, solubility and vapour pressure – plus five substance reactivity values – one

$$\begin{bmatrix} S_{ox} & S_{red} & S_{hse} & S_{hv} & S_{rad} \end{bmatrix} * \begin{pmatrix} \varepsilon_{ox\text{-}air} & \varepsilon_{ox\text{-}wat} & \varepsilon_{ox\text{-}soil} & \varepsilon_{ox\text{-}sed} \\ \varepsilon_{red\text{-}air} & \varepsilon_{red\text{-}wat} & \varepsilon_{red\text{-}soil} & \varepsilon_{red\text{-}sed} \\ \varepsilon_{hse\text{-}air} & \varepsilon_{hse\text{-}wat} & \varepsilon_{hse\text{-}soil} & \varepsilon_{hse\text{-}sed} \\ \varepsilon_{hv\text{-}air} & \varepsilon_{hv\text{-}wat} & \varepsilon_{hv\text{-}soil} & \varepsilon_{hv\text{-}sed} \\ \varepsilon_{rad\text{-}air} & \varepsilon_{rad\text{-}wat} & \varepsilon_{rad\text{-}soil} & \varepsilon_{rad\text{-}sed} \end{pmatrix} = \begin{bmatrix} k_{air} & k_{water} & k_{soil} & k_{sed} \end{bmatrix}$$

Figure 2. Matrix for calculation of compartmental reactivity of chemicals undergoing oxidations (ox), reductions (red), hydrolysis/substitution/elimination (hse), photochemical (hv) and radical (rad) reactions in air, water, soil and sediments. Matrix as suggested by Green and Bergman[5].

for each of oxidation (s_{ox}), reduction (s_{red}), hydrolysis (s_{hyd}), photolysis (s_{hv}) and reaction with radicals (s_{rad}). Under the proposed system for compartmental transformation rates the reactive nature of the environmental compartments are also defined and the degradation of any chemical within each of the defined environmental compartments is then calculated from the inherent chemical properties of the chemical (k_{air} k_{water} k_{soil} k_{sed}). The full theoretical discussion supported by equations is described in detail by Green and Bergman [5]. The combination of the transformation of the chemical, with respect to its dynamic partitioning in the fixed environment, within a multimedia fate model, provides a measure of the chemical's persistence. However, since the rates from the laboratory experiment are not directly applicable in the matrix (Figure 2) it is necessary to find standard compounds that can be related to the reaction rates measured. This work is still to be pursued.

The relative environmental importance of each type of the reactions has yet to be estimated. An attempt to present reactive power of oxidations, reductions, radical reactions, photochemical transformations and hse in air, water, soil and sediment is given in Table 1. The relative reactivity is presented with one to four +, representing low to high reactive power. A similar estimate may apply numerical values between 0 – 1 for estimation of compound specific stability/reactivity in the four compartments. To do this it is necessary also have a relative reactivity constant for the chemical compound under assessment, as mentioned above.

Table 1. Estimated reactive power of the five major reaction in the four environmental abiotic compartments.

	Air	Water	Soil	Sediment
Oxidation	+++	++++	+++	+
Reduction	+	++	++	++++
Photolysis	+++	+++	+	+
Radical reaction	++++	++	++	+
hse reactions	++	++++	++++	++

Assessing bioaccumulation Similarly to persistence, bioaccumulation is dependent on two major properties of the chemical species; its reactivity in biota, i.e. its susceptibility to be metabolised, and partitioning in an organism. The partitioning within an organism is evident if being a lipophilic neutral compound only undergoing passive partitioning. Bioaccumulation may as well be related to active transport mechanisms and binding making this type of bioaccumulation impossible to predict on a general basis. The latter type of bioaccumulation is dependent on biogenic molecular interactions with the actual chemical species. Compounds with the latter type of accumulation are shown by e.g. dioxins, metals, polychlorobiphenylols and PCB methyl sulfones[6,7]. Again, for highly hydrophobic compounds a general partitioning between fat and hydrophilic compartments of the body can be suggested based on D values (partitioning coefficient between octanol and physiological water). The

partitioning of a compound in biota and its chemical reactivity is a measure of its bioaccumulation potential. Since reactions are catalysed by enzymes *in vivo*, it is evident that transformations occur at a higher rate than abiotically. It is reasonable to discuss bioaccumulation from the two perspectives given here: Active and passive bioaccumulation, B_{act} and B_{pas}, respectively, only the latter to be predictable from chemico-physical and reactivity characteristics.

We suggest a methodology for measuring persistence and passive bioaccumulative potency. Applying this predictive methodology should lead to major improvements in risk assessments of chemicals and a tool for better management of chemicals.

References
1. UNEP. 2002. Switzerland, United Nations Environmental Programme Chemicals.
2. OECD. 1992. OECD Guidelines for testing of chemicals: 301 Ready biodegradability.
3. OECD 1981. OECD Guidelines for testing of chemicalsvol 1, no.3, 1-62.
4. Atkinson, R. *Atmospheric Chemistry and Physics* 2003, *3*, 2233-2307.
5. Green, N. and Bergman, Å. *Environ. Sci. Technol.* 2005, *39,* 480A-486A.
6. Letcher, R. J., Klasson Wehler, E. and Bergman, Å. Methyl Sulfone and Hydroxylated Metabolites of Polychlorinated Biphenyls. In *New Types of Persistent Halogenated Compounds*; Paasivirta, J., Ed.; Springer-Verlag: Berlin, 2000; Vol. 3, Chapter 11.
7. WHO Exposure of Potential EDCs in Humans and Wildlife. In *Global Assessment of the State-of-the-Science of Endocrine Disruptors*; Damstra, T., Barlow, S., Bergman, Å., Kavlock, R., van der Kraak, G., Eds.; International Programme on Chemical Safety, WHO: 2002; Chapter 6.