IMMOBILIZATION OF PHARMACEUTICALS IN SOILS

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Abstract

Worldwide production and consumption of pharmaceuticals increases every year. Due to the fact that these substances are not always completely eliminated in the human or animal body, subsequently get into the environment, which leads to a negative effect of certain constituents of natural ecosystems. Knowledge of contaminant behaviour is essential for their mobility and toxicity in the soils and surface- and ground-water environments. In this study, interactions of pharmaceuticals with soils and humic substances as the most important constituents of soil organic matter are investigated. Humic substances contain more types of active sites (hydrophilic functional groups and hydrophobic structures) able to bind different drugs and form relatively stable complexes with them. The complexation of drugs with soil organic matter thus can reduce their mobility and toxicity in natural systems. This study deals with interactions of soils and humic substances with drugs. the aim is to determine their binding capacity and stability of formed complexes with respect to the possible immobilization of drugs in the humic structure.

Keywords: Humic acids, soil, ibuprofen, stability

1. INTRODUCTION

In the European Union about three thousands different substances are used in human and veterinary medicine [1-3]. The persistence of these pharmaceuticals makes them ‘‘emerging pollutants’’ and stresses the need to advance waste and wastewater treatment technologies in addition to studying their potential effects in aquatic environments [1,4]. These substances are not completely eliminated in the body. It has been reported that 80 % of all consumed drugs are eliminated from the body unchanged, due their high stability against biological degradation [5-7]. These pharmaceuticals can therefore enter the environment. Some drug residuals were detected in surface and underground water [8-10] as well as in sediments and soils [12-16]. Because of their physical and chemical properties, many of these substances or their bioactive metabolites end up in soils and sediments, where they can accumulate and induce adverse effects in terrestrial or aquatic organisms [5,10,11]. Some pharmaceuticals may be removed by degradation. Laboratory studies show that degradation rates of pharmaceutical compounds in soils vary widely, with half-lives ranging from days to years. Within the same therapeutic class, half-lives can still be significantly different as a result of differences in soil properties [16-17]. Knowledge of contaminant behaviour is essential for their mobility and toxicity in the soils and surface- and ground-water environments.

The behaviour of pharmaceuticals in nature can be affected by their interactions with organic matter and humic substances as their most important constituents. Klavins et al. [1] determined the binding constants between humic acids and selected pharmaceuticals using a fluorescence quenching technique. Their findings suggest that an electrostatic interaction plays a dominant role in the complex formation between humic acids and pharmaceuticals, which was also confirmed by a salt effect and pH dependence of the fluorescence quenching effect. Khil´ko and Semenova [17] studied interactions of salts of humic acids with drug preparations. Their results were indicative mainly of binding between the charged groups of the macro-anions of humic acid salts and the positively charged centres of drug molecules (supplemented obviously by hydrogen bonds and hydrophobic interactions). They stated that the number of moles of drug preparations capable of interacting

with a natural humic macro-molecule was determined by their molecular structure peculiarities and charges. Margon et al. [18] investigated interactions of diclofenac with soil humic acids and resulted that they may led to the formation of diclofenac-humic supramolecules and micelles which can migrate through the coarse soil profile.

Kodešová et al. [19] measured sorption isotherms of several pharmaceutical substances on different soils. The simultaneous sorption experiments showed that the sorption affinity decreased with soil depth, i.e. with the content of soil organic matter. Lin and Gan [20] studied the sorption of diclofenac, ibuprofen, naproxen, sulfamethoxazole and trimethoprim in soils. They concluded that the poor sorption and relative persistence of diclofenac and ibuprofen under anaerobic conditions suggest that they may pose a high leaching risk when using recycled for irrigation or ground water replenishment. Martínez Mejía et al. [21] studied sorption mechanism of enrofloxacin on humic acids extracted from three Brazilian soils. They stated that the sorption of humic acids was higher in magnitude comparing soils from which they were isolated. The primary interactions were ionic and cation binding due to abundant carboxylic groups and H-bond moieties with carbohydrate-like structures. Liu et al. [22] studied adsorption behaviour and mechanism of ciprofloxacin and sulfamethoxazole. Their kinetics results indicated that the adsorption process included the fast-adsorption stage first and the slow-adsorption stage thereafter. Földényi et al. [23] dealt with adsorption of diclofenac on activated carbon in the presence of organic matter. They confirmed that the adsorption was enhanced by humic substances. Similarly, Kohay et al. [24] investigated the influence of humic acids on diclofenac binding on polycation-clay sorbents. Antilen et al. [25] proved that soil organic matter was capable of generating interactions with antibiotics, which resulted in a decrease in their availability.

Above-described high reactivity of soil organic matter is well-known and widely studied [26-29]. The sorption of pharmaceuticals to organic matter is an important mechanism related to their immobilization. The majority of studies dealing with interactions of drugs with organic matter were focused to the adsorption isotherms described by empirical Freundlich model used mainly for the physical character of binding, e.g. [19,25]. Some authors used also Langmuir model characterizing chemical adsorption in mono-molecular layer [24] or their combination [25]. The pollutants can be bound to soil organic matter by different strengths and three main fractions of them can be defined. First is the mobile fraction which is extractable by water, second fraction is ion-exchangeable and third is strongly bound [30,31].

2. MATERIALS AND METHODS

In this work, one of the most used drugs, Ibuprofen, and its interactions with three types of soil sampled in the Czech Republic were studied. Ibuprofen was purchased from Sigma-Aldrich. Soil A (phaeozem) was sampled in the region Jablůnka (closed to river Bečva), soil B (regosol) was sampled in the Hodonín (locality Pánov), and soil C (chernozem) was sampled in Brno (locality Slatina, closed to protected area Stránská skála). Samples A and B are arable soils with periodically changed arable crops as wheat and corn. Sample B is soil with grass vegetation included in the project of Technology Agency of the Czech Republic no. TH02030073. Basic characteristics of soil samples are in **Table 1** (elemental analysic was realised by means of EuroEA Elemental Analyzer EA 3000, Euro Vector; contents of moisture and organic fraction by means of thermogravimetric analyzer TGA Q50, TA Instruments).

Soil samples were mixed with the solution of ibuprofen (1 – 10 mg/dm^3), stirred (48 h) and centrifuged (Hettich ROTINA 46 R; 5000 rpm, 10 minutes). The ratio between the solid powder sample and solution was 0.5 g : 25 cm^3. Supernatants were filtered (0.22 μm) in order to remove solid particles and analysed by means of UV/VIS spectrometry (HITACHI U-3900H) in order to determine the residual amount of ibuprofen in solution after adsorption.

The stability of formed complexes were investigated by means of desorption experiments. Ibuprofen-soil complexes were mixed with 25 cm^3 of deionized water, stirred, centrifuged, filtered and analysed by the same methods as in the case of adsorption experiments.

Table 1 Elemental composition, moisture, and organic fraction of soil samples

Sample	C (wt.%)	H (wt. %)	N (wt. %)	O (wt. %)	moisture (wt. %)	org. fraction (wt. %)
Soil A	1.44	0.76	0.14	3.41	1.57	5.75
Soil B	0.45	0.12	0.03	0.57	0.22	1.17
Soil C	1.84	1.00	0.14	3.88	3.24	6.86

3. RESULTS AND DISCUSSION

In this work, the interactions between ibuprofen as a frequently used drug and three types of soils were investigated. Ibuprofen was prepared as its solution in deionized water. Soils were used in the form of solid powders. In **Figure 1**, the efficiency of adsorption for studied soil samples and adsorbed amount divided into mobile and residual bound fractions are shown. We can see, that the efficiency of adsorption is closely conned with the content of organic fraction in soil. The efficiency ranges between 49 and 83 % for soil A and between 42 and 89 % for soil C. These soils contain much higher amount of organic matter in comparison with sandy soil B. The efficiency is influenced not only by the amount of organic matter but also by its quality (composition, structure and properties). As mentioned above, electrostatic interactions can be considered as one of the major pharmaceutical binding mechanisms therefore the content of charged functional groups play crucial role in the immobilization of drugs in soils [1,21,23,35]. Klavins et al. [1]. correlated positively the binding of several pharmaceuticals with the content of carboxyl groups in humic acids (as the most important constituents of soil organic matter). On the other hand, hydrophobic interactions can play an important role in the adsorption of some drugs in dependence on their structure [1,35]. Földényi et al. [18] obtained isotherms with a breaking point resulting in the hypothesis of two adsorption steps: the first step related to the charge transfer interaction and the second one related to hydrogen bond formation.

The stability of complexes formed by adsorption was investigated by means of desorption of ibuprofen from humic acids and soil into deionized water. The fraction leached into water was regarded as the mobile fraction. The residual amount of ibuprofen was bound by ionic or covalent binds. In comparison with previous works [30,31], ibuprofen was divided only into two fractions in this study: the mobile fraction extractable by water, and residual bound fraction comprised of ion-exchangeable and strongly bound fractions.

We can see that the amounts of free mobile fractions are higher than residual bound fraction of ibuprofen in the case of sandy soil B with low content of organic matter. This type of coil is not able to bind strongly pollutants and the majority of them is bound only by means of weak physical forces. As expected, the amounts leachable into water were much lower for soil samples rich in organic matter (A and C). The efficiency of adsorption gradually decreased with the increasing concentration of ibuprofen for soil samples A and C. In the case of soil B the efficiency slightly increased for more concentrated solutions of ibuprofen (> 6 mg/dm^3). The increase did not influence the amount of bound fraction because the binding capacity of soil organic matter was exhausted. The binding sites (functional groups) are occupied and ibuprofen cannot be adsorbed by chemical or ion-exchange mechanisms. In contrast, the binding sites in soils rich in organic matter are covered gradually and no striking increase in physically bound ibuprofen was observed.

In spite of the fact that ibuprofen is adsorbed on soil surface by chemical and physical bonds, the well-known Langmuir adsorption isotherm [24,25,37] was applied on the experimental data and apparent adsorption capacity of soil samples was determined. Their values are stated **Figure 2** where the dependence of adsorption capacity on the content of organic matter in soils is shown. We can see that the capacity can be positively correlated with the content of organic matter. It surprising, that the dependence is strongly linear. In my opinion, it is partially caused by coincidence. The adsorption capacity is strongly influenced by many other factors as soil composition, structure, micro-organization and many other physical-chemical properties. However, it was confirmed that the higher contents organic matter in soils can improve their adsorption abilities and supported chemical interactions between ibuprofen and soil resulting in its stronger immobilization. The

ratio between contents of mobile and residual bound fractions increased generally with increasing concentration of ibuprofen. Its value strongly increased in the case of soil B as a result of higher physically bound drug. Soils rich in organic matter (A and C) had maximum of its value around 1 and no noticeable increase was observed in more concentrated systems.

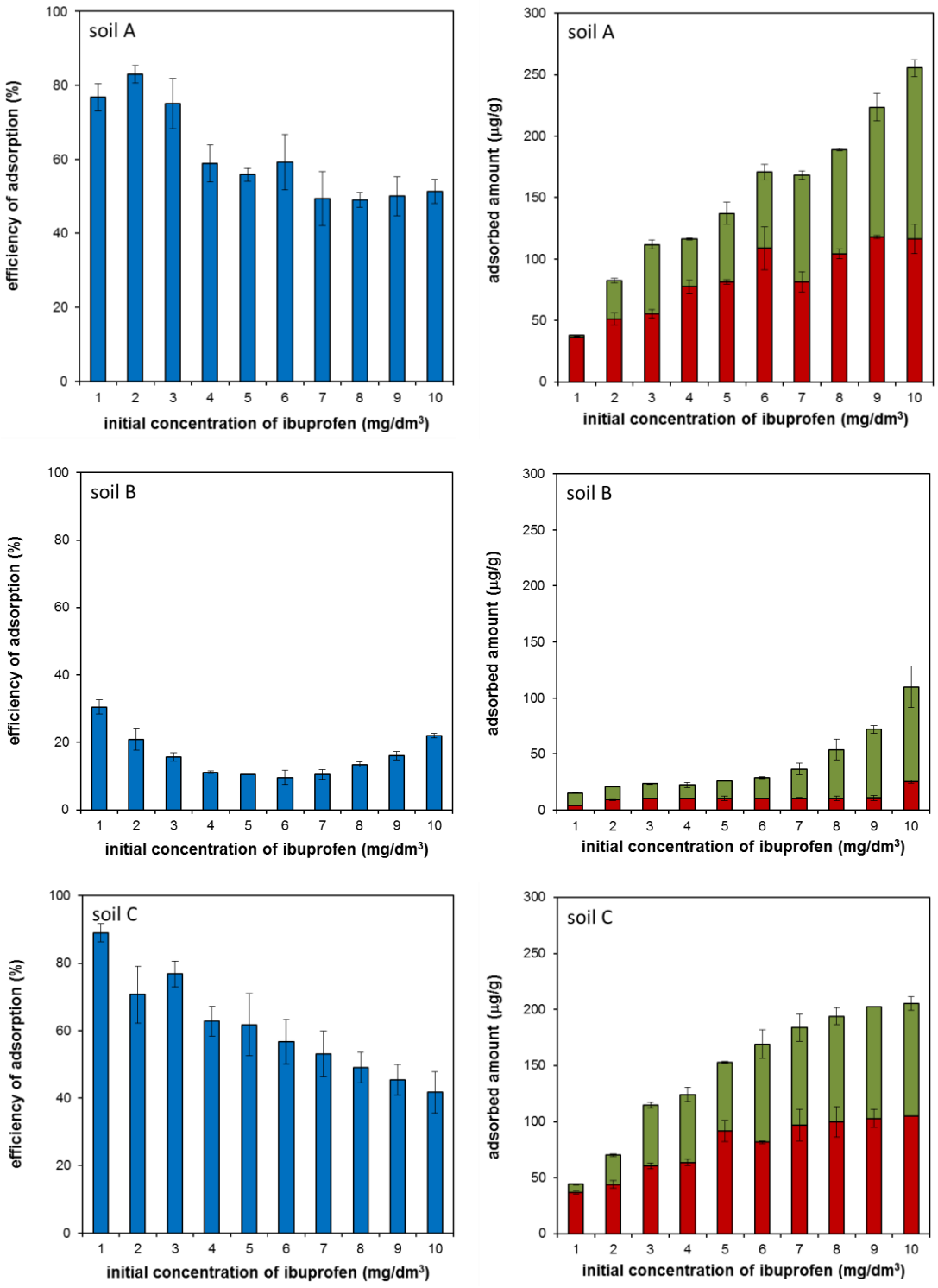

Figure 1 The efficiency of adsorption of ibuprofen on soils (left) and adsorbed amount of ibuprofen (right) divided into mobile fraction (green) and residual bond fraction (red): Soil A – up, B- amid, C –down

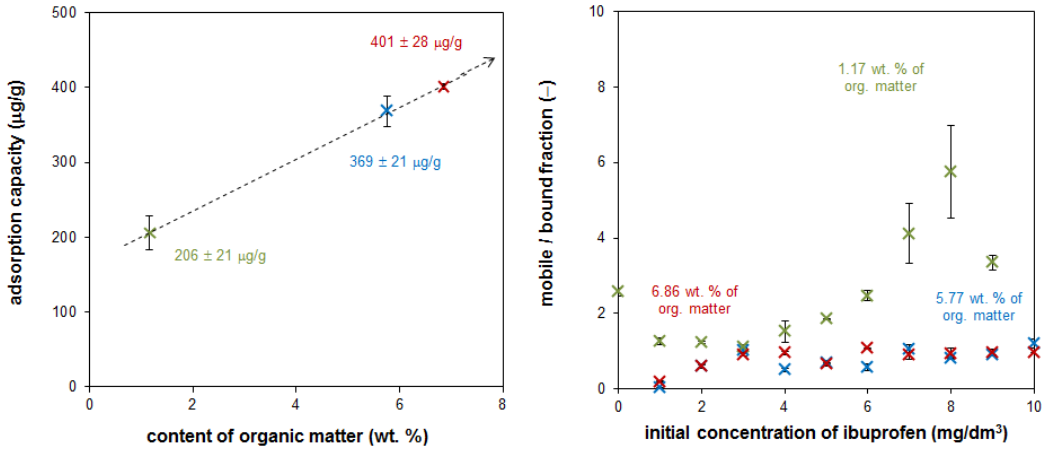

Figure 2 The dependence of adsorption capacity on content of organic matter in soils (left); ratio between mobile fraction of ibuprofen and its residual bound fraction (right):; soil A - blue, soil B - green and soil C - red

4. CONCLUSION

In this work, the interactions of soils with ibuprofen were investigated. It was found that the immobilization ability of soils was strongly influenced by the content of organic matter. The stability of formed complexes determined on the basis of leaching experiments confirmed that the binds between ibuprofen and organic matter are relatively strong. The mobility of ibuprofen in soils rich in organic matter can be effectively supressed by its immobilization.

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