SURFACTANT MODIFIED ZEOLITES –ADSORBENTS FOR MYCOTOXINS AND CARRIERS OF DRUGS

Aleksandra Daković
Institute for Technology of Nuclear and Other Mineral Raw Materials, Franchet d'Esperey 86,
P. O. Box 390, 11000 Belgrade, Republic f Serbia
E-mail: a.dakovic@itnms.ac.rs

ABSTRACT

The potential of surfactant modified zeolites as adsorbents for mycotoxins and as carrier of the pharmaceutical drugs was investigated. Ochratoxin A - OCHRA (mycotoxin) and diclofenac sodium - DS (anti-inflamatory drug) were used as model substances. Surface of the clinoptilolite was modified with different amounts of quaternary ammonium ions (hexadecyltrimethyl ammonium - HDTMA or octadecyldimethylbenzyl ammonium – ODMBA). For mycotoxin experiments, the amounts of surfactant at the zeolite surface were less and/or equal to the external cation exchange capacity (ECEC) of the zeolitic tuff, while for adsorption of drug, surfactant was added in amounts equal and/or above of the ECEC of the zeolitic tuff. Results showed that presence of organic cations at the zeolite surface increased adsorption of both OCHRA and DS. Their adsorption increased with increasing the amount of organic cations at the zeolitic surface.

Keywords: zeolites, surfactants, mycotoxins, drugs, adsorption

INTRODUCTION

Modification of clay minerals and zeolites with long chain organic cations – surfactants is undergoing the extensive study because of their potential use as environmental sorbents. Zeolite minerals have surface chemistry similar to clays, but display superior hydraulic properties. Hexadecyltrimethyl ammonium bromide (HDTMA-Br), octadecyldimethylbenzyl ammonium chloride (ODMBA-Cl), and cetylpyridinium chloride (CP-Cl) are commonly used surfactants [1, 2]. The surfactants can exchange inorganic cations only on the external surfaces of zeolites whereas in clays all exchangeable positions are equally available. Therefore, less organic phase is needed for zeolite modification [3].

The native exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) at the clinoptilolite surface can be replaced with the surfactants producing and organic carbon-enriched surface. The sorption of cationic surfactants onto negatively charged surface involves both cation exchange and hydrophobic bonding. At low loading levels (below the external cation exchange capacity of the clinoptilolite – ECEC), surfactant monomers are retained by ion exchange and eventually form a monolayer. As the amount of available surfactant increases (above ECEC), interactions among hydrocarbon tails cause the formation of a bilayer or patchy bilayer [4]. Possible arrangement of surfactants at the zeolite surface is presented in Figure 1.

Thus, chemical modification of zeolites with surfactants results in an increased hydrophobicity of the mineral surface providing the environment for retention of hydrophobic molecules. At sufficient surfactant loading a bilayer forms resulting in a charge reversal on the external surface providing sites where anions will be retained and cations repelled, while hydrophobic species can partition into the hydrophobic core [5].

Surfactant modified clinoptilolite was shown to be an effective sorbent of both organic compounds and inorganic anions from water. They may be also used as adsorbents for mycotoxins, and very recently they have been considered as carriers of pharmaceutical drugs

[6-8]. The objective of this research was to examine the possibility of using of surfactant modified zeolites as adsorbent for mycotoxins and as carrier for pharmaceutical drugs. Ochratoxin A (mycotoxin) and diclofenac sodium (anti-inflammatory drug) were used as model substances.

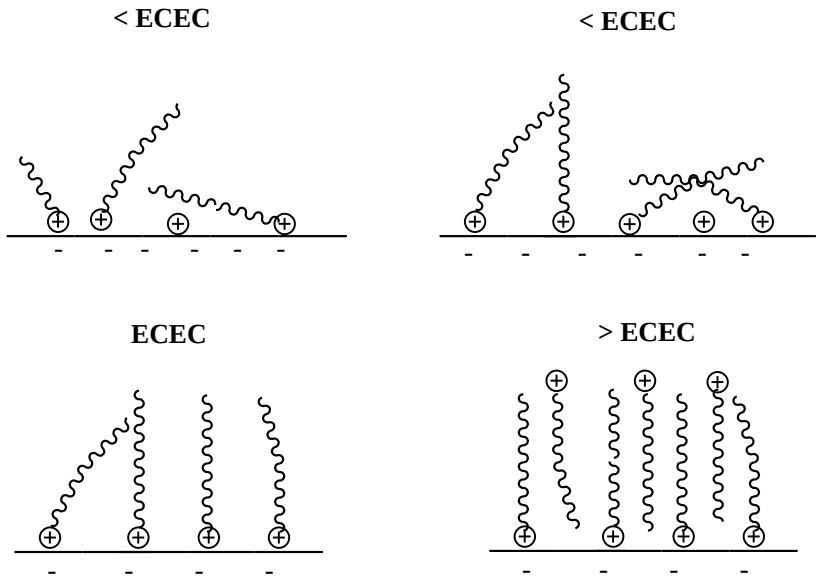


Figure 1. Surfactant sorption at the zeolitic surface, below and above ECEC of the zeolitic tuff.

EXPERIMENTAL

The starting material for obtaining the surfactant modified zeolites was a natural zeolitic tuff from the Zlatokop deposit (Vranje, Serbia). The mineralogical composition of the zeolitic tuff was primarily clinoptilolite (~80%) with small amounts of feldspar, quartz and pyrite as determined by qualitative X-ray powder diffraction analysis (Phillips PW-1710 diffractometer). After crushing and grinding the zeolitic tuff was sieved to yield particles below 0.063 mm. CEC of the starting material was CEC(M^+)=139 mmol/100g measured by the ammonium chloride method, while the ECEC was ECEC(M^+)=10 mmolM^+/100g determined using the method of Ming and Dixon [9].

The surface morphology of the natural zeolitic tuff was investigated using a JEOL JSM – 6460 LV scanning electron microscope (SEM). Before the scanning process, the sample was coated with gold to enhance the electron conductivity for the SEM investigation. Figure 2 presents the SEM micrograph of the raw zeolitic tuff [10]. Field observation and microscopic study of the sample revealed that the natural zeolitic mineral occurs predominantly as well-formed fine sized crystals. Many of well defined plates display tabular morphology characteristic for a monoclinic crystal system of clinoptilolite. The plates are commonly 25 to 50 nm in thickness and 0.2 to 1 μm in length.

The surfactant modified zeolites for mycotoxin adsorption experiments were obtained by treatment of the zeolitic tuff with ODMBA equivalents of 20, 50 and 100% of its ECEC (2, 5 and 10 mmolM^+/100g) and the obtained surfactant modified zeolites were denoted as OZ-2, OZ-5 and OZ-10. The surfactant modified zeolites as drug carriers were obtained by treatment of the zeolitic tuff with HDTMA-Cl in amounts equivalent to 100, 200 and 300% of its ECEC. The obtained composites are denoted as ZHB-10, ZHB-20 and ZHB-30. Details on the preparation and properties of surfactant modified zeolites are given elsewhere [8, 10-14].

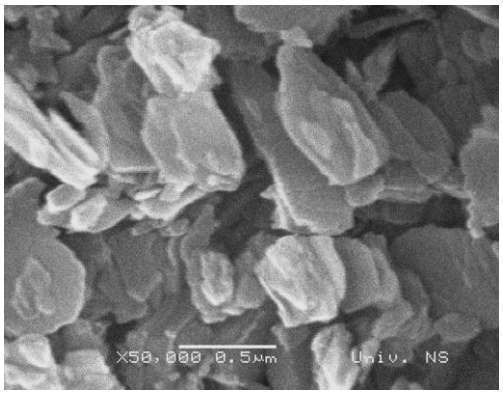


Fig. 2. SEM micrograph of the natural zeolitic tuff.

To investigate mycotoxin adsorption by the natural zeolitic tuff and the three organozeolites, duplicate aliquots of 0.1 M phosphate buffer (adjusted to pH 3 and 7) containing 2 ppm OCHRA in solution (10 ml) were added to 15 ml tubes to which had been added 40, 20, 10, 8 and 4 mg of each adsorbent. In order to eliminate exogenous peaks, controls were prepared by adding 10 ml of 0.1 M phosphate buffer (pH 3 and 7) plus 40 mg adsorbent to test tubes. Test tubes were placed on a rotator shaker for 30 min at room temperature. OCHRA test solutions and control were centrifuged and aqueous supernatant removed for OCHRA analysis. OCHRA concentrations in buffer solutions with and without adsorbents were determined by HPLC method [15].

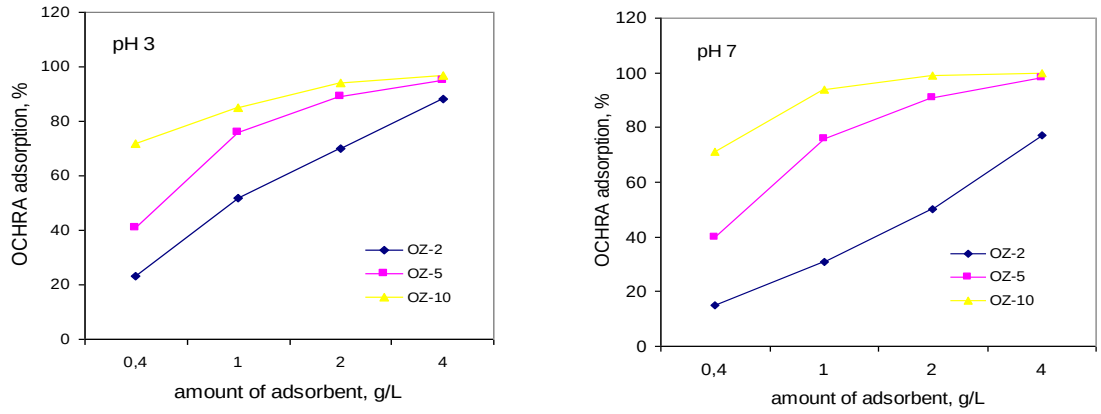
Adsorption of drug – diclofenac sodium (DS) by prepared composites was carried out in batch experiments. Stock solutions of the drug in the concentrations from 50 to 500 mg/l in phosphate buffer at pH 7.4 were prepared. The batch experiments were carried out by shaking the reaction mixture comprising 200 mg of each composite and 50 ml of drug solutions. After 1 h, the samples were centrifuged 15 min at 3000 rpm. The initial and unadsorbed concentrations of drug were determined by HPLC analysis [14].

RESULTS AND DISCUSION

Surfactant modified zeolites for OCHRA adsorption experiments were prepared by ion exchange of zeolitic tuff with ODMBA up to the ECEC value of the starting material – 10 mmol M^+/100 g. It has been shown previously that the measurement of inorganic cations and unreacted ODMBA content in the supernatant after ODMBA sorption, as well as the determination of the CEC of the modified organozeolites demonstrates that quantitative ion exchange had occurred [10, 11, 15]. For diclofenac sodium adsorption experiments, surfactant modified zeolites were prepared by addition of HDTMA in amounts ≥ ECEC value of the zeolitic tuff. Zeta potential measurement (results are not shown) of composites ZHB showed that when the amount of HB was equal to ECEC of the zeolitic tuff, zeta potential was close to zero suggesting almost monolayer formation and high hydrophobicity of the zeolitic surface. At HB amount equal to 200% and 300% of ECEC zeta potential becomes positive suggesting charge reversal and bilayer formation at the zeolitic surface [14].

Both OCHRA and DS are low polar organic molecules, less soluble in water. OCHRA consists of a dihydroisocoumarin moiety linked by an amide linkage to L-phenylalanine. The dissociation constant of the OCHRA carboxylic group is $pKa_1 = 3.5$ [16] and a dissociation constant of the phenolic group of OCHRA being $pKa_2 = 7$ [17]. Because OCHRA is organic compounds that contain different functional groups its adsorption by the zeolitic tuff and surfactant modified zeolites will vary with solution pH.

Based on the dissociation constants, OCHRA is present in solution partially in the anionic form at pH 3, while at pH 7, it is completely in the anionic form. Results obtained for OCHRA adsorption ($C_{0\ OCHRA}$ = 4.95 μmol/l; C_{susp} = 4 g/l)) on the zeolitic tuff (40% at pH 3 and 3% at pH 7 and 9) suggest some existing sites at the hydrophilic zeolitic surface on which nonionic form of OCHRA is adsorbed. However, presence of an organic cation at the surface of the organozeolite significantly increased the OCHRA adsorption at pH 3 and 7. Results of OCHRA adsorption by surfactant modified zeolites, at pH 3 and 7 are presented at Figures 3 a and b. OCHRA adsorption by surfactant modified zeolites OZ-2, OZ-5 and OZ-10 increased with increasing levels of solid phase in suspension and at the same concentration of each surfactant modified zeolite in suspension, OCHRA adsorption increased with increasing amounts of organic cation on the zeolitic surface. The highest adsorption of OCHRA was obtained with OZ-10 in which 100% of the inorganic cations at the surface had been replaced with ODMBA. Results indicate the degree of hydrophobicity plays a role in the adsorption of this hydrophobic molecule by surfactant modified zeolites [15]. Similar increase of adsorption with increasing the amount of organic phase at the zeolite surface was found also for mycotoxins - zearalenone and fumonisin B1 [10-13].



a) b)

Figure 3. Adsorption of OCHRA by surfactant modified zeolites OZ-2, OZ-5 and OZ-10 at pH 3 (a) and 7 (b).

In the preliminary experiment it was determined that the zeolitic tuff, due its net negative charge, was quit ineffective to adsorb DS [14]. Since DS is a hydrophobic organic molecules, it is assumed that may partition in the hydrophobic phase created by surfactant tail groups at the zeolitic surface. Drug adsorption by ZHB composites was studied through the determination of the adsorption isotherms, and these results are presented at Figure 4.

As can be seen from the Fig.4., adsorption of DS by ZHB composites followed nonlinear adsorption isotherms. It is observed that adsorbed amounts of DS increased with increasing the initial concentration of the drug in solution and also, the adsorbed amount of DS increased with increasing the amount of surfactant at the surface of ZHB composites. The results indicated that organic cations at the zeolite surface may be responsible for drug adsorption by ZHB composites [14]. Sorption of nonionic organic compounds by smectite minerals modified with large organic cations (HDTMA) is due to essentially linear solute partitioning into the hydrophobic phase formed by the large alkyl chains of the HDTMA ions and is presented with the linear adsorption isotherms, while nonlinear isotherms, indicative of adsorption or co-sorption, were observed when bentonite was modified with smaller organic cations (tetramethylammonium – TMA) [18, 19]. Shen (2004) [20] studied adsorption of relatively polar phenol on HDTMA- and benzyltrimethyl ammonium (BTMA)-smectites at pH 7. He reported a linear isotherm for adsorption of phenol on HDTMA-smectites, and a

nonlinear Langmuir isotherm for phenol adsorption on BTMA-smectite. Since HDTMA is a long chain organic cation, the nonlinear adsorption isotherms obtained for adsorption of diclofenac sodium to the ZHB composites may be an indication that the partitioning is not the only mechanism responsible for adsorption of this drug by the surfactants modified zeolitic tuff.

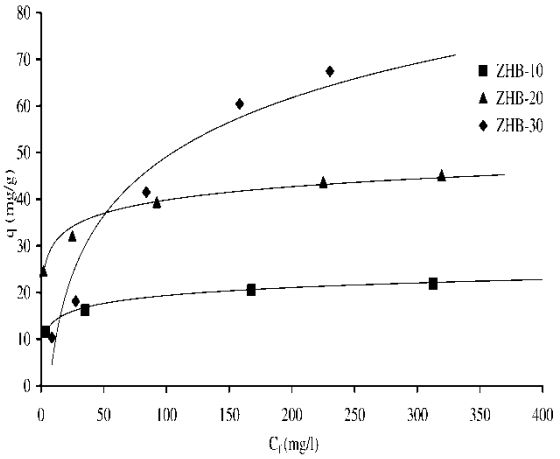


Figure 4. Diclofenac sodium adsorption by surfactant modified zeolites ZHB-10, ZHB-20 and ZHB-30

CONCLUSION

In this research, adsorption of model substances: ochratoxin A - OCHRA (mycotoxin) and diclofennac sodium – DS (anti-inflammatory drug) by surfactant modified zeolites was investigated. It was determined that surfactant modified zeolites were effective in adsorbing both OCHRA and DS. Adsorption of OCHRA and DS sodium increased with increasing the amount of surfactants at the zeolite surface. The binding efficacy of adsorbents for the mycotoxins and the drugs is dependent on their crystal structure and physical properties as well as on the physico-chemical properties (polarity, solubility, shape, charge distribution, dissociation constants, etc.) of the mycotoxins and the drugs. Since, the mycotoxins, as well as the drugs are organic molecules that contain different functional groups, for each molecule specific adsorption mechanism is expected. Thus, further research is needed in order to consider the surfactant modified zeolites for application in veterinary and pharmacy.

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