

Ciprofloxacin Binding Mechanisms on Goethite: A Molecular Dynamics Study

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Ciprofloxacin (CIP; $pK_{a1}=6.1$, $pK_{a2}=8.7$) is a commonly used broad-spectrum antibiotics that is now finding its way into natural aquatic and terrestrial environments. Studies focused on the fate of this emerging contaminant showed that CIP species bind on nanominerals of the iron oxide family via metal bonded (MB) surface complexation reactions [1-3]. Uncertainties however remain regarding the identity (carboxyl/keto vs. piperazine amine group) and binding modes of CIP functional groups at these mineral surfaces. In this context, Molecular Dynamics (MD) emerges as a powerful tool to resolve the nature of interactions between organic molecules and minerals at the atomistic scale [4].

To this end, we used free and biased MD simulations to resolve binding modes of three pH-dependent CIP species on four dominant crystallographic faces of goethite (α -FeOOH). We performed umbrella sampling simulations to evaluate the relative stability of various CIP species MB complexes proposed in the literature on different crystallographic faces. Using free MD, we identified hydrogen bond populations established between CIP functional groups and goethite surface (hydr)oxo groups. We find that the low pH CIP^+ species adsorbs less on goethite than $CIP^{+/+}$ and CIP^- , yet it forms more hydrogen bonds (HB) with reactive sites. This high content of hydrogen bonds between the CIP^+ species and the reactive sites would indicate that these HB complexes have a strong potential to become precursor of MB complexes. This may explain the greater adsorption of the CIP species at low pH observed in experiments. Our findings thereby add insight into the predominant binding mechanism of this important antibiotic, and therefore in predicting its fate and transport properties in nature

[1] Luo, T., Pokharel, R., Chen, T., **Boily, J.-F.**, & Khalil, H. (2023), *Environ. Sci. Technol.*, 57, 1, 214–221

[2] Martin, S., Shchukarev, A., Khalil, H., & **Boily, J.-F.** (2015), *Environ. Sci. Technol.*, 49, 20, 12197-12205

[3] Trivedi, P., & Vasudevan, D. (2007), *Environ. Sci. Technol.*, 41, 3153-3158

[4] Pedreira-Segade, U., Hao, J., Razafitianamaharavo, A., Pelletier, M., **Le Crom, S.**, Marry, V., Michot, L., & Daniel, (2018), *I. Life*, 8(4), 59

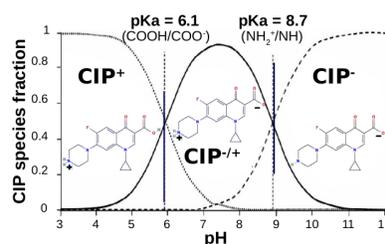


Figure 1. Ionic forms of CIP as function of pH

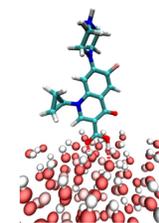


Figure 2. Snapshot of a CIP^+ HB complex