Ecological Engineering 120 (2018) 1–5

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Occurrence and removal of ibuprofen and its metabolites in full-scale constructed wetlands treating municipal wastewater

Tereza Dvořáková Březinova[a], Jan Vymazal[a,*], Milan Koželuh[b], Lumír Kule[b]

[a] Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Kamýcká 129, 16521 Praha 6, Czech Republic
[b] Vltava River Board, Holečkova 8, 152 00 Praha 5, Czech Republic

ARTICLE INFO

Keywords:
Sewage
Pharmaceuticals
Ibuprofen
Constructed wetlands

ABSTRACT

Ibuprofen (IBU) and its major metabolites, hydroxyibuprofen (OH-IBU) and carboxyibuprofen (CA-IBU) were monitored from November 2015 to March 2017 at four full-scale constructed wetlands with horizontal subsurface flow treating municipal wastewater in the Czech Republic. During the seven sampling campaigns, all three compounds were identified in high concentrations in the inflowing raw wastewater. The average inflow concentrations of IBU, OH-IBU and CA-IBU amounted to 14.6, 18.3 and 36.4 $\mu g\,l^{-1}$. The ratio between IBU, OH-IBU and CA-IBU is in agreement with the previously published results indicating that the ibuprofen metabolites occur in higher concentration in the raw wastewater than the parent compound with CA-IBU exhibiting the highest concentrations. The outflow concentrations off studied compounds decreased and removal amounted to 44.7%, 29.3% and 47.5% for IBU, OH-IBU and CA-IBU, respectively. The results are in line with general fact that ibuprofen and its metabolites are not removed with high efficiency in anoxic or anaerobic conditions and that OH-IBU is the least removed compound. The areal loadings of IBU, OH-IBU and CA-IBU averaged 0.425, 0.574 and 0.999 $mg\,m^{-2}\,d^{-1}$, respectively. The annual loads of all forms of ibuprofen varied between 458 and 958 $g\,year^{-1}$ among four studies constructed wetlands.

1. Introduction

The term *Emerging Pollutants* primarily refers to those pollutants for which no regulations currently require monitoring or public reporting of their presence in our water supply or wastewater discharges but which have the potential to enter the environment and cause known or suspected adverse ecological and (or) human health effects. The emerging pollutants belong to various groups of compounds with pharmaceuticals, personal care products, steroids and hormones, pesticides, food additives, abusive drugs, fire retardants, nanoparticles and cyanotoxins being the most important emerging pollutants.

Pharmaceuticals have been released to the wastewaters and/or surface waters for decades, however, the occurrence of pharmaceuticals in surface waters and wastewaters started to attract public attention when sufficient analytical methods were available for emerging aquatic micropollutants determination in the late 1970s (Hignite and Azarnoff, 1977; Richardson and Bowron, 1985; Rogers et al., 1986). Scientific interest in pharmaceuticals occurrence in the water environment was largely connected with the concern over possible toxicological risks and implications stemming from human exposure via drinking water, development of antibiotic resistant bacteria, feminization of male fish and toxicity and genotoxicity in aquatic organisms (Jones et al., 2001; Kostich and Lazorchak, 2008; Benotti and Brownawell, 2009; Loganathan et al., 2009).

Many pharmaceuticals are designed to be persistent and lipophilic so they can retain their chemical structure in the organisms (usually human or domestic animals) long enough to do their therapeutic work. Consequently, after excretion such chemicals can persist in the environment and enter the food chain through bioaccumulation and biomagnifications (Daughton and Ternes, 1999; Loganathan et al., 2009). Pharmaceuticals do not have acute toxicity effects on aquatic organisms because their low concentrations, in the order of ng-µg/l, but often, they may show subtle effects for their continuous introduction in the environment acting as pseudo-persistent pollutants (Calamari et al., 2003; Isidori et al., 2009. Then, the ecotoxicological potential of pharmaceuticals and their residues remains almost unknown.

Human pharmaceuticals enter the water environment primarily through human excretion into wastewaters (Ternes, 1998; Fent et al., 2006). Lesser routes include disposal of unused medicines (Kostich and Lazorchak, 2008). Many pharmaceuticals undergo metabolic transformation within the human and animal bodies and metabolic transformation products are excreted and enter surface waters either directly or

* Corresponding author.
E-mail address: vymazal@fzp.czu.cz (J. Vymazal).

https://doi.org/10.1016/j.ecoleng.2018.05.020
Received 1 March 2018; Received in revised form 13 May 2018; Accepted 14 May 2018

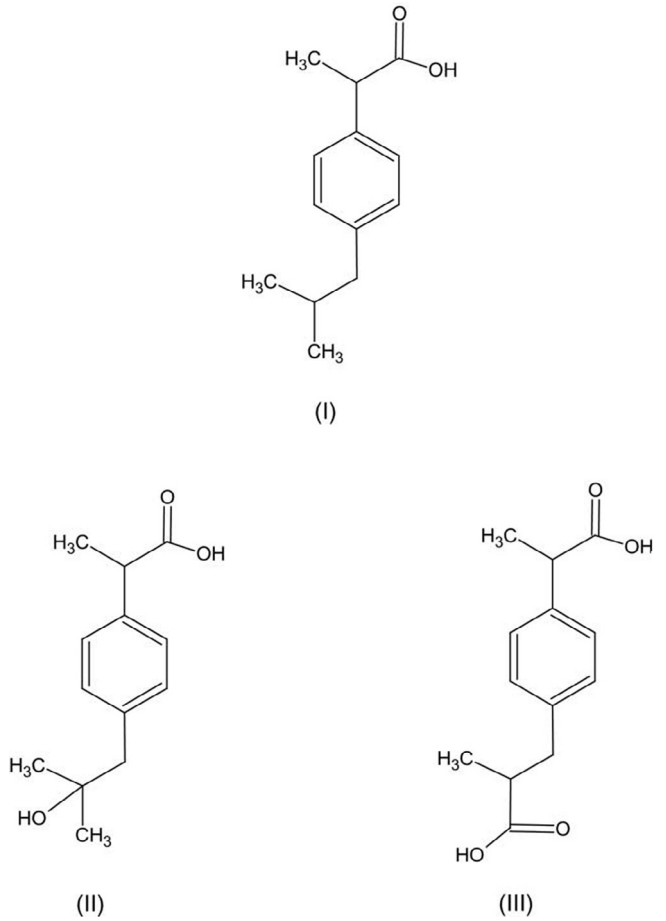

Fig. 1. Ibuprofen (I) and its major metabolites hydroxyibuprofen (II) and carboxyibuprofen (II) (Shyadehi and Harding, 2002).

through wastewater treatment plants effluents (Mompelat et al., 2009). It has been shown that metabolites may potentially pose greater risk than their parent pharmaceuticals (Han and Lee, 2017).

Ibuprofen (2-(4-Isobutylphenyl) propionioc acid) is a nonsteroidal anti-inflammatory drug (NSAID) that is used for treatment of pain and inflammation and reduction of fever. Ibuprofen was patented in 1961 (Garrard, 2014) and it is sold under various names such as Advil, Ibalgin, Brufen, Dolgit, Nurofen or Motrin. Ibuprofen (Fig. 1) is one of the most studied pharmaceuticals in constructed wetlands (e.g. Matamoros and Bayona, 2006; Matamoros et al., 2009; Reif et al., 2011; Breitholtz et al., 2012; Vymazal et al., 2015; Li et al., 2016) and it occurs in high concentrations in municipal sewage. The inflow concentrations are commonly found in tens of micrograms per liter (Vymazal et al., 2015), however the inflow concentration can reach levels up to several hundreds $\mu g\ l^{-1}$ (Santos et al., 2009).

The metabolism of ibuprofen involves conjugation with glucuronic acid and oxidation to yield two major products (Fig. 1), hydroxyibuprofen (2-[4-(2-hydroxy-2-methylpropyl)phenyl] propionic acid) and carboxyibuprofen (2-[4-(2-carboxypropyl)phenyl]propionic acid) (Tan et al., 1997). Other metabolites such as 1-hydroxyibuprofen, 3-hydroxyibuprofen and several glucuronic acid conjugates can be also present in urine but at very low concentrations (Buser et al., 1999; De Oliveira et al., 2005; Ferrando-Climent et al., 2012). It has been reported that only about 15% of ibuprofen is excreted unaltered while carboxyibuprofen (CA-IBU) and hydroxyibuprofen (OH-IBU) account for 43% and 26% of total ingested ibuprofen (Ferrando-Climent et al., 2012). These authors pointed out that, some of the ibuprofen metabolites can be the result of biodegradation.

Zwiener et al. (2002) reported that ibuprofen is transformed into CA-IBU under both aerobic and anoxic conditions while OH-IBU is formed only under aerobic conditions. Removal of ibuprofen in constructed wetlands has been reported variable depending on the type of constructed wetland used (Zhang et al., 2012a,b; Matamoros et al., 2009; Ávila et al., 2010; Reif et al., 2011; Matamoros and Salvadó, 2012; Breitholtz et al., 2012).

The objective of this study was to evaluate occurrence and removal of ibuprofen and its major metabolites at four full-scale constructed wetlands treating municipal sewage in the Czech Republic

2. Materials and methods

The survey was performed at four full-scale constructed wetlands treating municipal wastewater. The systems were described in detail in Vymazal et al. (2017). All the systems were designed with subsurface horizontal flow and served 55 (C), 132 (A), 196 (B) and 248 (D) PE. The filtration material is either crushed rock (A) or washed gravel (B, C, D) and *Phragmites australis* was used either as a single species (A, B) or in combination with *Phalaris arundinacea* (C, D). The constructed wetlands have been in operation between 11 and 25 years during the monitored period.

The samples of raw sewage and the outflow were taken seven times between November 2015 and April 2017 (11/2015, 2,6,9,11/2016, 1,3/2017). The composite 4-h samples were taken in 60 ml amber glass vials and samples were stored in a freezer. On the day of analysis the samples were defrosted at max. 30 °C and the analyses were carried out immediately after defrosting.

The sample was centrifuged in headspace vials for 5 min at about 3500 rpm. Then, exactly 1.50 g of the sample were weighed into a 2 ml vial on the analytical balance. After that, 1.5 µL of acetic acid was added into the sample. An isotope dilution was performed in the next step with deuterized internal standard of d_3-ibuprofen was used. Pharmaceuticals were separated and detected by LC-MS/MS methods based on the direct injection of sample into chromatograph. A 1200 Ultra High-Performance Liquid Chromatograph (UHPLC) tandem with 6410 Triple Quad Mass Spectrophotometer (MS/MS) of Agilent Technologies were used in ESI- mode. The separation was carried out on a Water XBridge®-C-18 analytical column (150 × 4.6 mm, 3.5 µm particle size). Mobile phase consisted of methanol and water with 0.05% acetic acid as mobile phase additive. The flow rate was $0.25\ ml\ min^{-1}$. Injection volume was 1 ml. The surrogate recoveries were always higher than 90%. Limits of quantification were $20\ ng\ l^{-1}$ for ibuprofen and CA-IBU and $30\ ng\ l^{-1}$ for OH-IBU. Statistically significant differences between inflow and outflow concentrations of monitored compounds were determined by paired Student t-tests ($\alpha = 0.05$).

3. Results and discussion

Ibuprofen as well as both metabolites OH-IBU and CA-IBU were detected in high concentrations during all samplings at all four constructed wetlands (Fig. 2). The average inflow concentrations of ibuprofen varied between 6.1 $\mu g\ l^{-1}$ and 27.1 $\mu g\ l^{-1}$ among monitored constructed wetlands. The average inflow IBU concentration was 14.6 $\mu g\ l^{-1}$ and the highest recorded inflow concentration was 110 $\mu g\ l^{-1}$. The average inflow concentrations recorded in our study are within the range reported in the literature for raw municipal wastewater. Lindqvist et al. (2005) reported an average ibuprofen concentration of 13.1 $\mu g\ l^{-1}$ in seven wastewater treatment plants in Finland, the average concentration of 8.45 $\mu g\ l^{-1}$ was reported by Lishman et al. (2006) as an average concentration from 12 wastewater treatment plants in Canada. In Spain, Carballa et al. (2004, 2008) reported inflow concentrations in the range of 3.7–19 $\mu g\ l^{-1}$ and Santos et al. (2009) reported the concentrations up to 603 $\mu g\ l^{-1}$. The inflow concentrations of both metabolites were mostly higher than that of ibuprofen. The average inflow concentrations of OH-IBU was 18.3 $\mu g\ l^{-1}$