The elimination of selected pharmaceuticals in wastewater treatment – lab scale experiments with different sludge retention times

M. Clara[1], B. Strenn[1], O. Gans[2] & N. Kreuzinger[1]
[1]*Institute for Water Quality and Waste Management, Vienna University of Technology, Vienna, Austria*
[2] *Federal Environment Agency Ltd., Vienna, Austria*

Abstract

The effluent of sewage treatment plants had been shown to be a significant source for pharmaceutical residuals in surface waters. The sludge retention time (SRT) is the most important parameter for the design of wastewater treatment plants. To study the influence of this design parameter on the elimination of selected pharmaceuticals lab scale experiments with different SRT (1 d, 12–15 d and 30 d) were performed. Common pharmaceuticals for different applications, in particular two antibiotics (Roxythromycin, Sulfamethoxazole), two analgesics/antiphlogistics (Diclofenac, Ibuprofen), the antiepileptic Carbamazepine, the contrast media Iopromide, the tranquilizer Diazepam and the lipid regulator Bezafibrate were selected.

In the plant running with a SRT of 1 d no significant elimination was observed. By increasing the SRT lower effluent concentrations can be reached. For some of the substances (Bezafibrate and Ibuprofen) only a slight increase of the SRT causes a complete elimination and a clear dependency from the SRT can be stated. Others of the observed compounds (Carbamazapine) passed the bioreactor without any changes.

1 Introduction

Large quantities of pharmaceuticals are used both in human and in veterinary medicine. Pharmaceuticals are used for application with humans or animals and

serve to alleviate, to prevent or recognize diseases, pains, body damages or pathological disturbances [1]. In January 2002 in Austria altogether 11,567 medicines for human applications with approx. 1,800 different active ingredients are accredited. The number ob the admitted veterinary products amounts to 1,055 [2]. Due to our highly developed health system considerable quantities of pharmaceuticals are prescribed annually, whereby for several active compounds peak values of more than 100 t/a are reached.

Drugs are excreted mainly via urine or faeces in unchanged form, as metabolites or glucuronides and by these pathways they enter row sewage. Some pharmaceuticals are used in ointments and get into wastewater directly by washing off. Another emission pathway of pharmaceuticals into wastewater is the inappropriate disposal over toilets. As another important source of environmental intake, the manufacturers have to be considered.

Over the collection of the wastewaters these substances arrive into sewage treatment plants. In the case of an incomplete elimination they enter surface waters via treatment plant effluents. Other contaminating sources for the aquatic environment are landfill leachates and leakages in the sewer system. Also drugs for veterinary applications have to be considered, which enter groundwater or surface waters via run offs, liquid manure or dung.

In order to derive basic knowledge on the behaviour of these substances during different steps of wastewater treatment lab-scale experiments were performed. The aim was to investigate the influence of different sludge retention times (SRT) on the elimination of the selected pharmaceutics.

The SRT describes the mean residence time of the activated sludge in the system and is related to growth rate of the microorganisms. Therefore the installation of a certain SRT determines the development of a specific biocoenosis. A high SRT supports slow growing bacteria which are known to have the ability to establish elimination pathways for the degradation of persistent substances. This relationship between SRT and purification makes the sludge retention time to the most important parameter for the design of biological wastewater treatment plants.

Beside of the microbial degradation substances can also be eliminated by adsorption to the activated sludge from the liquid phase. The removal of the substances from the system which are adsorbed on the sludge occurs with the excess sludge.

2 Selected substances

Two antibiotics (Roxythromycin, Sulfamethoxazole), two analgesics/antiphlogistics (Diclofenac, Ibuprofen), the antiepileptic Carbamazepine, the contrast media Iopromide, the tranquilizer Diazepam and the lipid regulator Bezafibrate were selected. They are figured in the following Table 1 and the quantities consumed in Austria in 1997 [3] are shown.

Table 1: Examined drug compounds and quantities consumed in Austria in 1997.

Pharmaceutical group	Active compound	Consumption [kg/a]
Analgesics/Antiphlogistics	Diclofenac	6143
	Ibuprofen	6696
Tranquilizer	Diazepam	125
Lipid regulator	Bezafibrate	4474
Antiepileptic	Carbamazepin	6334
Antibiotics	Sulfamethoxazole	963
	Roxithromycine	No data available
Contrast medium	Iopromide	5386

Analgesics/Antiphlogistics are medicaments with paregoric and anti-inflammatory effects and they belong to the most prescribed pharmaceuticals. About 60 % of Diclofenac are excreted via urine as glucuronides and less than 1 % in unchanged form [5]. Ibuprofen is used predominantly as anti-inflammatory agent and is very diffused, because it's also contained in many no prescription requiring analgesics.

Diazepam is a tranquilizer and also used as antiepileptic agent. The substance is better known under the trade name Valium®. Carbamazepine is an antiepileptic and represents the basic therapeutic agent for epilepsy illnesses. Carbamazepine is metabolized in the human body and only 2-3 % of the given dose is excreted in unchanged form.

From the big group of the antibiotics the active substances Sulfamethoxazole and Roxithromycine are examined. The sulfonamide Sulfamethoxazol as well as the macrolide antibiotic Roxithromycin inhibits bacterial growth.

Bezafibrate is a lipid regulator, which affects the fat metabolism or the fat resorption. It's used to lower high cholesterol levels, one of the main factors of risk for arteriosclerosis. Bezafibrate is excreted mainly via urine, 50 % of the administered dose in unchanged form and 20 % in form of glucuronides [4].

Iopromide is an iodine containing contrast medium. Contrast media are substances, which will be more or less absorbed by X-rays than from the neighbouring body tissues. Therefore they are used for X-ray representations of special body parts. Iopromide will not be metabolized in the human body and is excreted mainly via urine (98 %).

3 Materials and methods

3.1 Determination method

Two different detection methods were used for the analysis of the above mentioned compounds. Ibuprofen, Diclofenac and Bezafibrate were separated and analysed by GC-MS detection after derivatisation with diazomethane and a clean up step by silica gel chromatography. LC-MS-MS was employed for the analysis of Roxithromycine, Sulfamethoxazole, Carbamazepine, Diazepam and

Iopromide. Ionisation of the analytes was done by electrospray ionisation in positive mode.

Prior to the sample extraction a surrogate standard (josamycine, tylosine and dihydrocarbamazepine or meclofenamic acid) was added to the samples. Two different solid phase extraction phases (cyclohexane (CH)- and ENV+ - phase) were employed for LC-MS-MS sample preparation. The samples were acidified in the case of the C-18 and CH – solid phase extraction cartridges, whereas the addition of a neutral EDTA buffer solution was necessary for the ENV+ phase. The water samples were extracted and enriched by C-18 solid phase cartridges prior to the analysis with GC-MS.

To overcome problems due to ion suppression in the LC-MS method, recoveries of the surrogate standard and measurements of multiple dilutions of the extracts were performed.

3.2 Lab-scale experiments

Lab-scale continuous flow experiments have been performed. These experiments were started to determine the dependence on different sludge retention times (SRT) of the elimination rates of the selected substances. Three different SRT have been investigated (1 d, 15 d and 25 d).

The lab scale plant running with a SRT of about 1 day has been operated as a SBR (Sequenced Batch Reactor). At the beginning the reactor was filled with activated sludge from the Vienna main Wastewater Treatment Plant, which is a high loaded activated sludge plant operating with a SRT of about 1 day.

For the experiments run with higher SRT compact lab scale plants with a total volume of 10 l were used (bioreactor about 8 l, final sedimentation about 2 l). The used bioreactors operated as conventional activated sludge systems. To start the test facilities they were filled with activated sludge of a low loaded municipal wastewater treatment plant.

The bioreactors were fed with synthetic wastewater and a known quantity of the selected pharmaceuticals has been added. The concentrations were chosen according to a previous monitoring study in a range observed in influents of existing wastewater treatment plants [3]. The use of synthetic wastewater has the advantage that defined and constant influent conditions can be guarantied.
The synthetic wastewater was mixed according to the indications in the German Standard Methods. The composition of the medium is shown in the following Table 2 and 3.

Table 2: Characterization of the synthetic wastewater.

Parameter	Concentration [mg/l]
COD (Chemical Oxygen Demand)	506±47
TOC (Total Organic Carbon)	128±44
TN (Total Nitrogen)	47.9±10.3
TP (Total Phosphourus)	7.4±2.4
PO4-P (Posphate)	5.6±2.9

Table 3: Concentrations of the selected substances in the influent.

Diclofenac	4,0 µg/l	Carbamazepine	4,0 µg/l
Ibuprofen	2,0 µg/l	Sulfamethoxazole	2,0 µg/l
Diazepam	1,0 µg/l	Roxithromycin	2,0 µg/l
Bezafibrate	4,0 µg/l	Iopromide	1,0 µg/l

The hydraulic loading rate amounted about 4.5 l/d for all test-facilities. Due to this the hydraulic retention time corresponds to one day for the SBR and to about two days for the plants with SRTs of about 15 and 25 days respectively.

While the SBR was aerated continuously, the aeration of the other bioreactors was time regulated in order to allow intermittent nitrification and denitrification. Excess sludge was removed every day. The daily measurement routine included temperature, pH and oxygen content.

In dependency of the SRT a typical biocoenosis can be established. To allow this and to reach an equilibrated system, the plants were operated over a lead time of two to three SRT periods. During these lead times once a week samples were taken to describe and to control the process. During the sampling campaigns daily composite samples were taken. Thereby the parameters COD (Chemical Oxygen Demand), nitrogen and phosphorus were analysed. A plausibility check of the data has been performed by mass balances.

4 Results and discussion

Mass balances of the test facilities were calculated to illustrate the stability of the systems. To compare the results of the three systems the sludge retention time related to 20°C ($SRT_{20°C}$) was calculated for each reactor. This calculation based on the COD mass balance, the temperature in the bioreactor and a correction coefficient (f_P=1,072) for the temperature.

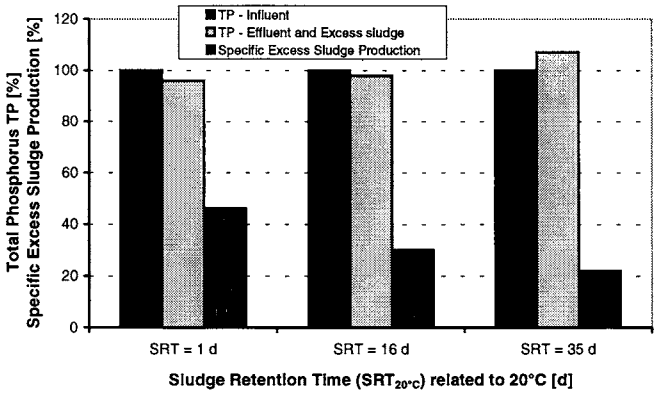

Figure 1: Results of the phosphorus mass balance of the three bioreactors, COD rate of the excess sludge dependent on the Sludge Retention Time related to 20°C.

The phosphorus mass balance is an adequate instrument for the control of the different mass flows. Phosphorous is not degraded biologically and therefore the load in the influent has to be equal to the sum of phosphorus in the excess sludge and the effluent load. The results of the phosphorus mass balance are shown in Figure 1. Also shown is the part of the COD eliminated via the excess sludge. This specific excess sludge production decreases with increasing SRT. This decrease of the excess sludge production is due to the higher endogenous respiration of the activated sludge during low loading rate. Especially in lab-scale plants which are fed with synthetic wastewater the specific excess sludge production is lower than in full scale plants because the synthetic influent doesn't contain any solids [5].

Figure 2 to Figure 4 display the results of the mass balances for the selected substances and the three bioreactors.

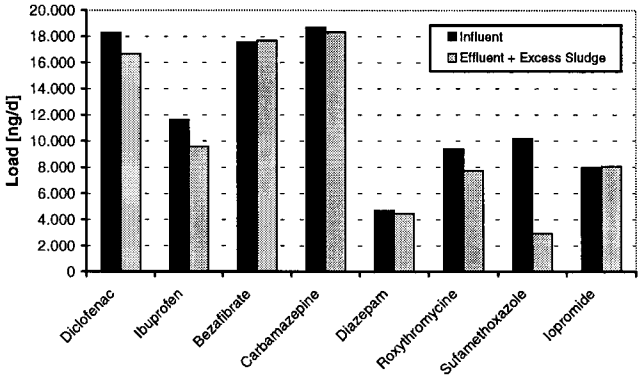

Figure 2: Influent and effluent load of the selected pharmaceuticals, Sludge Retention Time (20°C) 1 d.

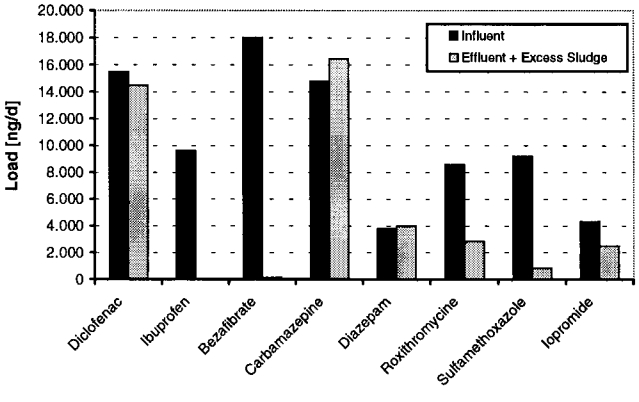

Figure 3: Influent and effluent loads of the selected pharmaceuticals, Sludge Retention Time (20°C) 16 d.

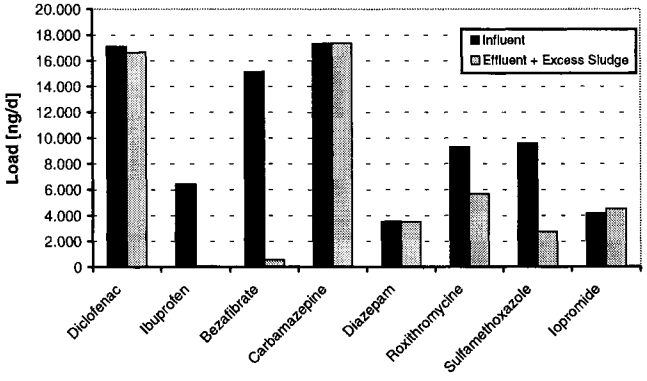

Figure 4: Influent and effluent loads of the selected pharmaceuticals, Sludge Retention Time (20°C) 35 d.

In the plant operated with a SRT of one day no significant eliminations could be detected. Only the antibiotic Sulfamethoxazole reached an elimination rate of more than 70 %. The removal rates for the two analgesics were very low and reached 18 % for Ibuprofen and 9 % for Diclofenac.

Bioreactor 2 operated with a higher SRT of 16 days (related to 20°C). In this plant some of the investigated substances showed a significant elimination. The concentrations for Ibuprofen and Bezafibrate in the effluent reached the detection limit whereas the elimination rate amounted up to more than 98 %. A further increase of the removal compared to plant run with the $SRT_{20°C}$ of 1 day could be detected for the antibiotics Roxythromycine and Sulfamethoxazole. Roxythromycine was removed up to 67 % and Sulfamethoxazole up to 90 %.

The third lab scale plant run with a SRT of 35 days (related to 20°C) showed no significant differences compared to the results of the bioreactor run with a $SRT_{20°C}$ of 16 days.

Only Diclofenac showed to behave in another way. In comparison to the plants running with lower SRT the removal of Diclofenac decreased. Since several substances like Diclofenac are assumed to be eliminated mainly by adsorption onto the sludge, the excess sludge production is vitally important. The specific excess sludge production decreases with the increasing SRT (see also Figure 1). In an equilibrated system the daily excess sludge production represents the available adsorbent. Therefore the adsorbent capacity is decreasing when the SRT increases.

Due to this dependency it is obvious that a decreasing sludge production causes a decrease of the removal rates for this substance because the adsorption capacity also decreases. Therefore it can be assumed that an improvement of the elimination of Diclofenac dependent on a higher SRT is rather improbable. The results of bioreactor 3, operated with a $SRT_{20°C}$ of 35 days confirm this assumption. In the following Figure 5 the relation of the elimination charge of Diclofenac dependent on different SRT is shown.

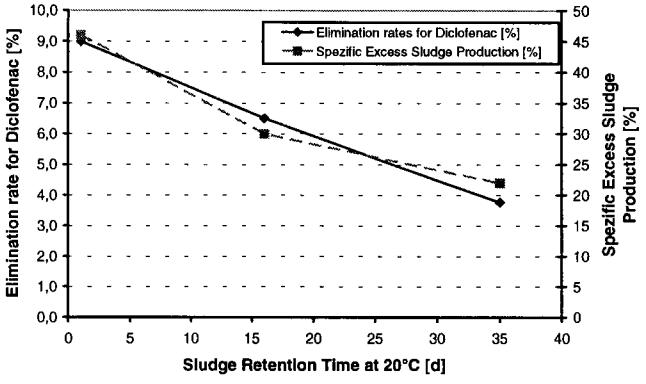

Figure 5: Elimination quantity of Diclofenac in relation to the specific excess sludge production in dependence on the sludge retention time at 20°C.

Concerning Carbamazepine and Diazepam no significant removal between influent and effluent was detected. Those two substances seem neither to be degraded or metabolised nor to be adsorbed. Even an increase of the $SRT_{20°C}$ up to 35 d did not show any effect.

An interesting behaviour could be detected for Iopromid. This substance passed plant 1 ($SRT_{20°C}$) and plant 3 ($SRT_{20°C}$) without any visible reduction whereas in plant 2 ($SRT_{20°C}$) a significant elimination occurred. Similar effects were investigated for the two antibiotics. The removal rates for Roxythromycine reached 40 % and for Sulfamethoxazole nearly 70 %. The experiment run with a $SRT_{20°C}$ of 16 days showed higher elimination rates for both substances. This is difficult to explain, but it's possible that the influent load has been overestimated as a consequence of analytical skills.

Recapitulating three different comportments concerning the SRT dependency of the investigated substances could be detected (compare Figure 6):

- Some substances like Diazepam and Carbamazepin pass the wastewater treatment plant without any adsorption, degradation or modification.
- The elimination rates of the antibiotics and the contrast medium Iopromid increased, augmenting the $SRT_{20°C}$ from 1 day up to 16 days. A further increase of the $SRT_{20°C}$ up to 35 days resulted in a decrease of the elimination for these substances.
- A complete elimination of the substances Bezafibrate and Ibuprofen was investigated with a $SRT_{20°C}$ higher than 15 days. It can be assumed that the Monod-relation is appropriate for the description of the elimination behaviour of these substances during wastewater treatment.

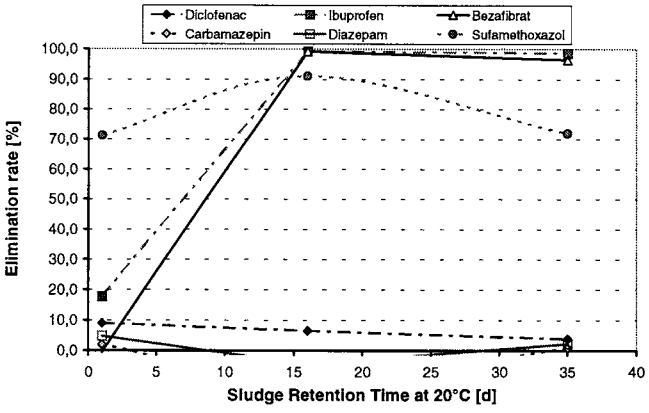

Figure 6: Elimination rates of the investigated pharmaceutics in relation to the sludge retention time at 20°C.

5 Summary

Concerning the investigated pharmaceuticals different elimination rates were detected. Bezafibrate and Ibuprofen appeared to have the best removal. For these substances a significant dependence of the degradation on the sludge retention time was determined. For the other investigated substances no clear SRT dependency could be observed. To approve the results reported in this study, further experiments with a $SRT_{20°C}$ of about six to eight days will be performed. Furthermore investigations on existing wastewater treatment plants will be done.

Recapitulating two groups of substances can be differentiated. On one hand those substances with clearly decreased effluent concentrations related to the influent. On the other hand we have substances, e.g. Carbamazepin, which pass the different steps of the wastewater treatment without any significant alteration.

An exception seems to be Diclofenac. This substance showed none or only slight elimination rates during the lab scale experiments. This results doesn't fit with data reported from full scale treatment plants, where elimination rates up to 50% were measured.

Finally it has to be observed that for this study only filtrated samples were analysed. Thus only the soluble fraction of the substances was detected. Most of the investigated substances show very good water solubility but some of them are poorly water soluble, e.g. Diclofenac. In such a case it is possible that the influent quantity is underestimated because the suspended solids are not comprehended in the analyses. Therefore fractions which are adsorbed to these suspended solids are missing. Further no exact separation between degradation and removal because of adsorption to the sludge can be determined. Another option which was neglected, are possible intermediate fractions. Consequently substances which metabolises were not detected in the effluent medium.

The maybe higher risk potential of these metabolites compared to the basic substances should not be underestimated.

This report presents first results of the investigations concerning the behaviour of selected pharmaceutics in wastewater treatment. As there is a multitude of substances (about 1.800 accredited in Austria) it's not possible to analyse all of them. Therefore a priority list in dependency of the ecological relevance should be elaborated. For this a detailed risk assessment is necessary. Future investigations should also include a study of the elimination pathways, because possible intermediates can even have more toxic effects than the default substance. One possible way could be the grouping of substances with similar chemical/physical properties. Further investigations could concentrate on representatives of these groups and should include a risk assessment of emissions from wastewater treatment plants. Should appear any indications that these emissions are relevant for the aquatic environment, suitable solutions for an efficient risk minimization have to be investigated.

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