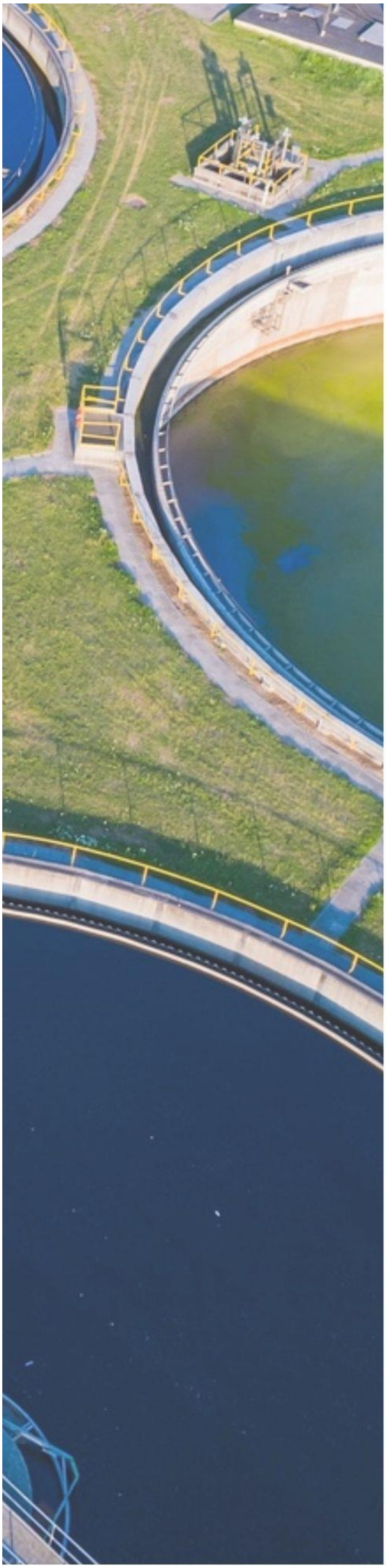

Less is More

Energy-efficient technologies for removal of pharmaceuticals and other contaminants of emerging concern

Deliverable No: 3.3

Polish demonstration unit – preliminary concept design

Foreword

This report is part of the project LESS IS MORE - Energy-efficient technologies for removal of pharmaceuticals and other contaminants of emerging concern. The project was financed by the Interreg South Baltic Programme 2014-2020, through the European Regional Development Fund. The Swedish partners' participation in the project was co-financed by the Swedish Agency for Marine and Water Management.

Partners in the project are: Lund University, Department of Chemical Engineering; Sweden Water Research AB, Kristianstad University, Slagelse Utility, Slagelse Municipality, JSC "Kretinga Water" and Gdansk Water Foundation.

The project started 1st of January 2018 and completion date was 30th of June 2021.

The specific project objective was to demonstrate, test and validate - new technological solutions for removing pharmaceuticals and other CECs as well as antibiotic-resistant bacteria that are suitable for small and middle-sized WWTPs, and to disseminate information on new technologies to the end-users.

This deliverable presents a preliminary concept design for Polish demonstration unit in Słupsk WWTP for removal of pharmaceutical residues and other organic micropollutants. The document serves as a starting point for a potential and more detailed design of a process solution based on GAC-filtration considering local conditions. Preliminary concept design is based on Slagelse and Svedala WWTPs cases and detailed information from Less is More national reports (Deliverable 4.1).

This report was written by project external experts: prof. dr hab. Ewa Siedlecka and Bartosz Łuszczek - Technology and innovation Director in WWTP in Krakow and in cooperation with all project partners: Department of Chemical Engineering of Lund University, Sweden Water Research AB, Kristianstad University, Slagelse Utility, Slagelse Municipality, JSC "Kretingos vandenys" and Gdansk Water Foundation

Gdańsk, 30th of June 2021

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Introduction

Pharmaceutical residues and other EDCs (the endocrine-disrupting chemicals (EDCs) discharged from our society to the environment adversely affect aquatic ecosystems. Studies have also shown that antibiotics in the environment may contribute to the increase of antibiotic resistant genes in bacteria, which is a serious threat to our possibility to cure life-threatening diseases on the global scale. The negative effects of pharmaceuticals on the ecosystem include hormonal disorders and behavioural changes. Pharmaceutical residues and other EDCs are spread through WWTPs and action is thus needed at the WWTPs. A key problem, however, is the lack of energy efficient solutions for removal of micropollutants without generation of potentially harmful transformation products. Degradation of micropollutants, for example, by ozonation is possible but may cause a formation of potentially harmful transformation products, known and unknown. By applying technologies based on separation, rather than degradation, effects of transformation products can possibly be avoided. Less is More project focuses on Granular Activated Carbon (GAC) filtration and GAC is the core process in the three pilot units in Denmark, Lithuania and Sweden. In Sweden, a concept with Direct Membrane Filtration (DMF) has also been investigated.

The long-term aim of the project is to reduce the input of such substances from wastewater into the Baltic Sea through by upgrading of WWTPs. The specific project objective is to pilot – demonstrate, test and validate – new technological solutions, for removal of pharmaceuticals and other EDCs as well as antibiotic-resistant bacteria that are suitable for small and middle-sized WWTPs and to disseminate information on new technologies to the end-users.

Actions are needed in all targeted countries to fulfil the integrated implementation of the common directives (Environmental quality standards Directive also known as the Priority Substances Directive, WFD, MSFD) and the common strategy frameworks (EUSBSR, EU2020).
The benefit for partners is multiple: gain of knowledge by pilot-scale testing and sharing of knowledge by cross-border collaboration among utilities (end users), universities and technology providers. Cross-border collaboration will enable exchange of experiences on wastewater treatment in general and the integration of advanced treatment methods in particular which will be beneficial for future upgrades of wastewater treatment plants around the Baltic Sea.

Moreover, the project will increase interaction between end-users and the research community. The technical competence and knowledge is high within the research community. However, the implementation rate of required technology is still slow at the WWTPs. This project contributes to the transfer of knowledge from the research community to the decision makers at municipal and WWTP levels. The pilots will serve as demonstration plants to other coastal municipalities and WWTPs on solutions and design criteria for removal of micro-pollutants that are possible on full-scale applications at WWTPs within the region.

The aim of this work is to deliver a preliminary concept design for a demonstration unit at a WWTP in Poland. A collaboration with Słupsk was initiated to be used as a starting point in order to describe a future, potential solution suitable for a Polish plant like the one in Słupsk. Such a solution, concept design, can be based on the large-scale pilot plant in Slagelse, which has been successfully operated for more than a year.

In the following, a structure for the concept design is suggested based on discussions and notes from the starting meeting. The structure and the content should just be considered as a starting point and can be adjusted.

Polish conditions in general

Wastewater treatment in Poland in general – important aspects

The number of 651 WWTPs operate with more stringent treatment (N & P removal) in Poland based on Urban Wastewater Treatment National Programme Report 2018-2019 (PGW Wody Polskie, 2021). Some historical reasons caused that almost every WWTP > 100 000 PE uses combined biological and chemical P removal, which is specific compared to other EU countries. General Polish quality standards in effluent for WWTPs >100000 p.e commonly are based on 91/271 directive with COD<125mg/dm3, BOD5<15mgO2/dm3, TSS<35 mg/dm3, total nitrogen<10 mg/dm3 and total phosphorus< 1 mg/dm3. The biggest challenge for Polish WWTPs for next few years is to achieve a full compliance with 91/271 directive and to prepare for new targets defined in ongoing UWWTD revision, also concerning micropollutants.

Due to less stringent effluent standards than in Denmark and Sweden for N and P, in Poland also higher organic matter concentration in treated wastewater is observed. DOC is not commonly used as a parameter in Poland but basing on COD, the mean value of 15 mg/L of DOC can be used as common value for effluent in Polish conditions. It is about 50% higher value than in Sweden and Denmark.

Pharmaceuticals in wastewater

The OECD health expenditure statistics show that Polish households spent almost four times more in 2020 when compared to 2015 on over-the-counter medicines than on prescribed medicines. The expenditure on over-the-counter medicines has been growing more rapidly in Poland than in other European countries (Sowada et al., 2019). Moreover, the available data indicate that Poland has one of the highest rates of total consumption of antibiotics among European countries.

The range of pharmaceutical concentrations in raw wastewater in Poland is from a few ng L^{-1} to over 200 µg L^{-1}. According to reports, the average concentrations of naproxen, diclofenac, ketoprofen and ibuprofen in influent is in range 48.4- 94.2 µg L^{-1}, 13.3 - 16.9 µg L^{-1}, 8.1 - 10.7 µg L^{-1}, and 9.5 - 5.2 µg L^{-1}, respectively. Sulfamethoxazole, is detected at concentration levels of 5597 ng L^{-1} in influent and up to 6000 ng L^{-1} in treated wastewater. Oxazapam and carbamazepine are found in the inlet to WWTP in 0.11 µg L−1, and 1.7 µg L^{-1}, respectively (Styszko et al.,2021).

Up till now, in the EU and Poland, the municipal treatment plants have not been designed to remove drugs and their metabolites. Conventional wastewater treatment plants based on mechanical and biological stages use denitrification, aerobic and anoxic chambers in biological reactors, able to remove readily biodegradable organic matter and biogenic compounds (N and P removal). Thanks to changeable oxygen conditions, microorganisms of active sludge remove contaminants by decomposing them into simpler substances or using them as building materials and reserves. During wastewater treatment, EDCs may be adsorbed on the suspended solids, biodegraded, chemically degraded and removed from the wastewater. However, the common WWTPs are not able to efficiently remove poorly biodegradable micropollutants such as pharmaceuticals.

The removal efficiency of EDCs in conventional WWTP varies in a wide range depending on the chemical structure of compound, quality of influent, operational conditions of WWTP, season of the year, or microbial composition. The high removal efficiency was noted for ketoprofen (over 95%) and naproxen (over 99%). Estrogens were also effectively removed, because natural estrogens (E1 and E2) belong to highly biodegradable compounds under aerobic and anoxic conditions. The most difficult was the removal of diclofenac, clofibric acid and carbamazepine as these substances showed low biodegradability. Clofibric acid can be removed from 26 to 50%. Diclofenac revealed a low and varied removal rate ranging from 10 to 50%. The average removal of carbamazepine in WWTPs showed large variations. In several cases, the effluent concentrations were higher than the influent concentrations, probably due to deconjugation of carbamazepine, which resulted in negative removal efficiencies in the WWTPs.

An increase of concentrations of endocrine-disrupting chemicals (EDCs) in the effluent from WWTPs is observed for about 18% - 20% of all detected EDCs. The significant values of negative efficiency removal were observed in Kraków WWTPs for fexofenadine (ca. 70%), venlafaxine (19–28%), o-desmethyltramadol (ca. 200%), ketamine (45%), and temazepam (37–47%). The increase in final effluent concentrations of the compounds likely results from dissolution of persistent contaminants accumulated in aggregates and/or back-transformation or de-conjugation of metabolites into parental compounds (Verlicchi et al., 2012a; Petrie et al., 2015; Petrie et al., 2016; Archer et al., 2017). The higher concentrations of venlafaxine recorded in the effluent can be connected with a transformation of the metabolites, desvenlafaxine, and two glucuronides into the parental compound and/or it's released to the water phase from sewage sludge. It was found, that Venlafaxine concentration is 2, 3 times higher in sewage sludge than in the water phase. Tramadol is released to sewage as two primary metabolites O-desmethyltramadol and N-desmethyltramadol (Ardakani and Rouini, 2007), and only 10–30% is discharged in sewage as the native tramadol (Ardakani and Rouini, 2007). Temazepam and oxazepam are also related to predominant excretion in the form of conjugates followed by cleavage to unchanged drugs during treatment (Fitzgerald, 2009).

The EDCs migrate to surface water ecosystems from point sources including wastewater treatment plants. Even low concentrations of EDCs, and short-term exposures of aquatic organisms to these compounds, can induce a variety of negative physiological effects. They can accumulate in the tissues and be transferred to higher trophic levels with the food chain, which makes them extremely hazardous to health or life of organisms, including humans. Diclofenac is characterized by the highest toxicity amongst non-steroidal anti-inflammatory drugs and shows chronic toxicity. Therefore they are considered "new" hazardous environmental pollutants. The studies showed that pharmaceuticals were also identified in the samples taken from the Polish rivers and drinking water. The presence of diclofenac sodium in Polish rivers was found at following concentration: 380 ng/dm3 (the Warta river), 470 ng/dm3 (the Odra river), 140 ng/dm3 (the Vistula river), while Naproxen was found at the concentration of 100 ng/dm3 i(the Warta river). Moreover, the presence of naproxen and diclofenac was identified in drinking water at the concentrations of 13 and 4 ng/dm3 respectively. The samples were taken in Poznan. Surface water and drinking water in Poland as well as in other countries in EU showed also the presence of illegal drugs.

Tests of technology plant based on: aeration, I step sand filtration, ozonation, II step sand filtration, GAC sorption were conducted in Jaworzno WWTP (125000 p.e.) located in Upper Silesia region (Kosiniak M. 2019). During the tests, reduction of diclofenac concentration from 114 ng/dm3 to

<0,2ng/dm3 was observed, but there was no reason for such low concentration after clarifier. A year before it was 3329 ng/dm3 (mean value). Pilot plant was built in 2019-2020. Due to COVID-19 pandemic test were stopped. After restart, efficient micropollutants reduction was observed. Papers concerning detailed information are in progress.

The Słupsk case

Slupsk WWTP

Slupsk WWTP treats wastewater collected from Słupsk city and municipalities: Słupsk and Kobylnica and basis on combined sewers system. Plant is designed for 230 000 p.e. and average flow of 28 200 m^3/d. Treatment process bases on conventional active sludge for N and P removal supported with P precipitation with iron sulphate. Sludge handling includes thickening and mesophilic digestion with external organic co-substrates pasteurized waste. Dewatered sludge is treated in composting process. Compost is allowed to use in agriculture.

In 2019, daily flow varied from 10600 m^3/d to 41070 m^3/d with 20536 m^3/d average. Słupsk WWTP reduces COD by 97%, BOD by 99% and total nitrogen by 84% and total phosphorous by 95%.

The endocrine-disrupting chemicals (EDCs) removal in Slupsk WWTP

The concentration of 32 micropollutants in wastewater influent and effluent from WWTP in Slupsk and their removal efficiency were shown in Figure 1 and in Figure 2, respectively.

The highest concentration in the wastewater influent was found for paracetamol (30.0 µg/L), diclofenac (3.4 µg/L), azithromycin (3.1 µg/L), and carbamazepine (1.7 µg/L). Ibuprofen, ciprofloxacin, metoprolol, naproxen, furosemide, tramadol, and losartan were in the significant concentration in influent but in the range 0.7- 1.2 µg/L. Other micropollutants were at a concentration lower than 0.4 µg/L. Some pharmaceuticals such as naproxen, ibuprofen or diclofenac in influent to Słupsk WWTP were at a lower concentration than those found in raw wastewater of big cities such as Kraków.

The highest efficiency removal in WWTP in Słupsk was found for paracetamol (99.8%), ketoconazole (97.3%), naproxen (96.7%), estrone (95.7%), and sertraline (90.1%). The lower efficiency removal but still higher than 80% was reached for bisphenol A (88.2%), ciprofloxacin (89.1%), and losartan (87.2%).

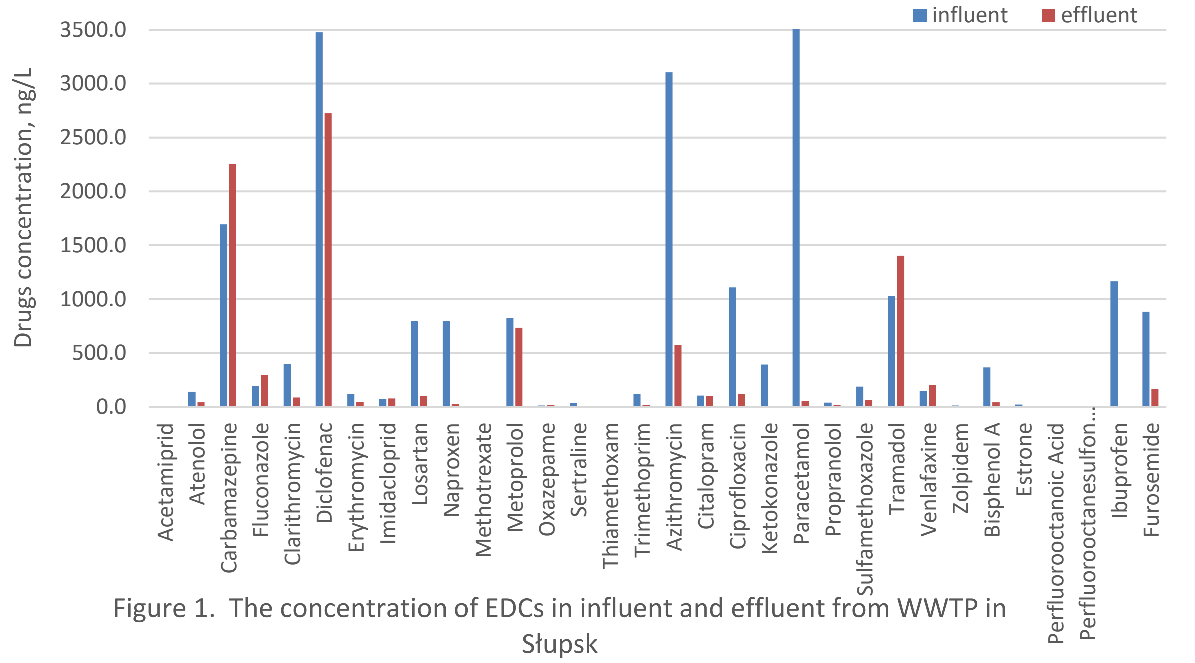

Figure 1. The concentration of EDCs in influent and effluent from WWTP in Słupsk

The increase of concentration In wastewater effluent was observed for carbamazepine (from 1.7 to 2.2 µg/L), tramadol (from 1,0 to 1.4 µg/L, fluconazole (from 0.2 to 0.3 µg/L) , venlafaxine (0,15 to 0.20 µg/L), oxazepam (from 0.014 to 0.015 µg/L) and imidacloprid (from 0.076 to 0.079 µg/L) . The increase of these drugs concentration could be connected with the release of native compounds from their metabolites such as glucuronates after biological treatment. The negative efficiency of these EDCs removal trends was also found in other WWTPs in Poland and in abroad.

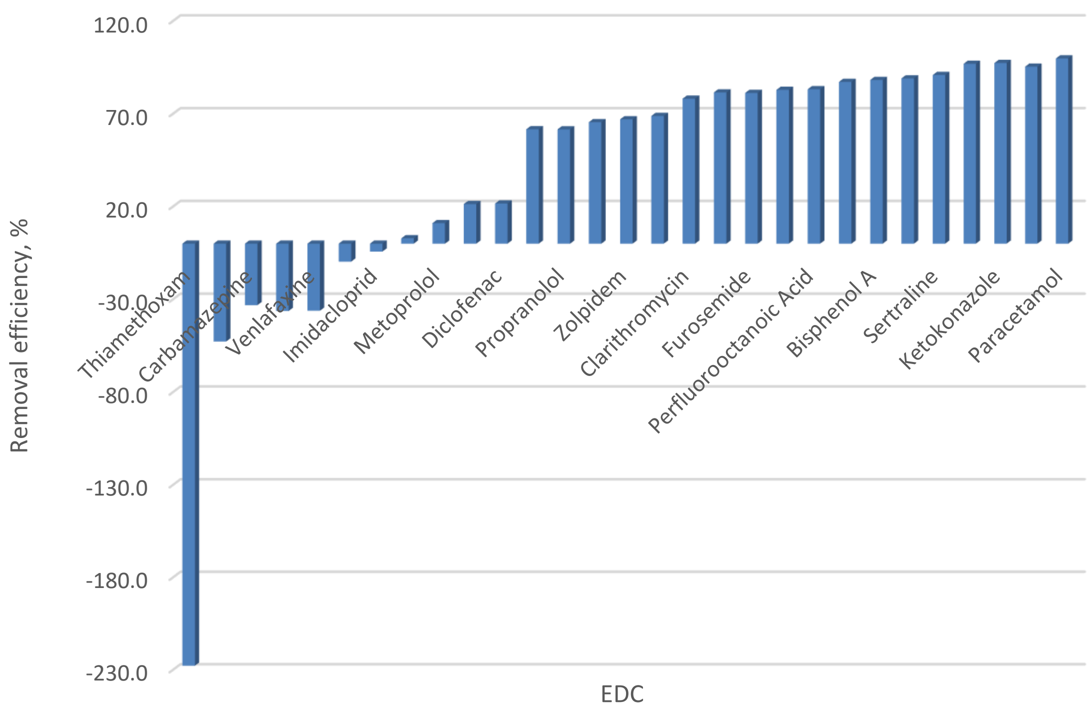

Fig.2. Removal Efficiency of EDCs in WWTP in Słupsk

The effluents from WWTP in Slupsk are discharged to the Słupia River. The increase of micropollutants concentration downstream of the river compared to the upstream, before the discharge of treated wastewater to Słupia river informs us about the stability of micropollutants in the environment and the their degree of pollution in the water.

In the upstream, atenolol (19 ng/L), carbamazepine (1.1 ng/L), clarithromycin (4.4 ng/L), thiamethoxam (1.2 ng/L), ketoconazole (3.6 ng/L), propranolol (3.1 ng/L), sulfamethoxazole (6.8 ng/L), tramadol (0.9 ng/L), and bisphenol A (0.3 ng/L) were identified. This indicates that they existed in the river before the effluent from WWTP in Słupsk was discharged (Fig.3).

The downstream concentration of atenolol (0.7 ng/L), clarithromycin (2.1 ng/L), thiamethoxam (below detection limit bdl), ketoconazole (bdl), propranolol (bdl), sulfamethoxazole (3.6 ng/L), and bisphenol A (bdl) was lower than in the upstream - indicating that self-purification processes of water participated to the micropollutants removal, due to their low concentration in the effluents discharged from WWTP.

In contrast to this, the increase of the concentration of the following drugs: carbamazepine from 1.1 ng/L to 58.8 ng/L, fluconazole from 0 to 5.7 ng/L, diclofenac from 0 to 54.7 ng/L, erythromycin from 0 to 2.7 ng/L, imidacloprid from 0 to 1.7 ng/L, losartan from 0 to 2.6 ng/L, metoprolol from 0 to 12.9 ng/L, trimethoprim from 0 to 1.7 ng/L, azithromycin from 0 to 4.2 ng/L, citalopram from 0 to 1.4 ng/L, paracetamol from 0 to 4.2 ng/L, tramadol from 0.9 to 31.3 ng/L, venlafaxine from 0 to4.3 ng/L, estrone from 0 to 0.6 ng/L, furosemide from 0 to 3.5 ng/L was observed downstream of WWTP. The elevation of some EDCs concentration and appearance of some EDCs downstream suggested that effluents from WWTP are the source of these pollutants in river water. It is surprising that some of these micropollutants are in very low concentration (lower than 40-100 ng/L) in effluent discharged from WWTP, (e.g. erythromycin, imidacloprid, paracetamol, and estrone). It is possible that WWTP is not the only source of micropollutants in this place. Some micropollutants discharged by WWTP into the river in a concentration lower than 100 ng/L did not influence the quality of river water (e.g. atenolol, clarithromycin) downstream.

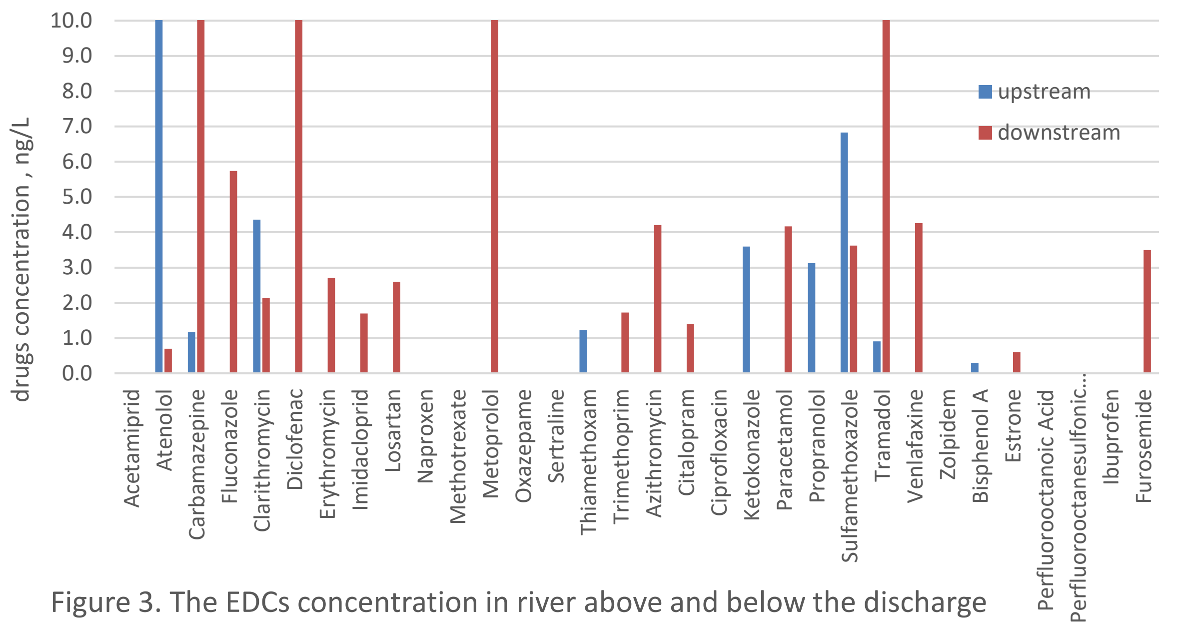

Figure 3. The EDCs concentration in river above and below the discharge of sewage

The Slagelse case

This description (including figures and tables) is based on the National Danish report, deliverable 4.1 and 4.2.

Short description of the WWTP

Slagelse WWTP is a conventional WWTP with activated sludge for nitrogen and phosphorous removal (Fif. 4). The capacity is 125,000 PE, and the daily load is approximately 60,000 PE. Total flow per year is typically 4,000,000 m^3. The average sludge retention time is 13 days, and the hydraulic retention time in the biological step is about 49 hours. An extra separate biological step – the Activated Return sludge Process (ARP) - treats the reject water.

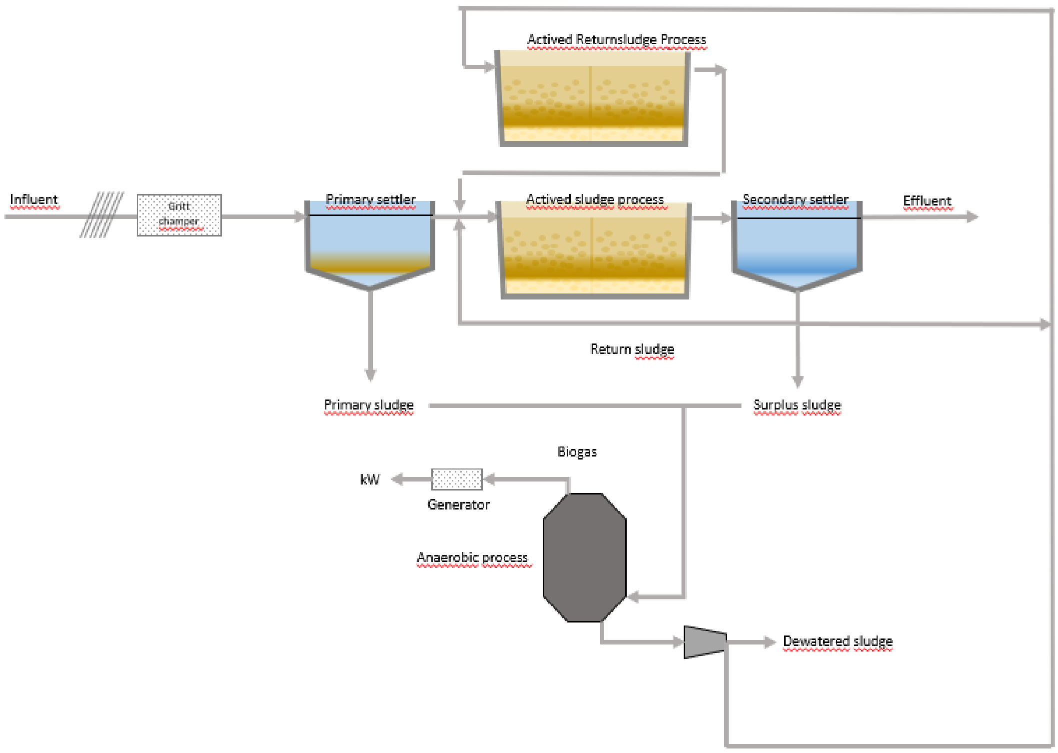

Figure 4. Overview process scheme of Slagelse WWTP

Slagelse WWTP reduces COD by 97%, BOD by 99% and total nitrogen by 91% and total phosphorous by 94%. DOC-content in effluent water is 7-9 mg/L. General Danish quality standards in effluent are: 75 mg COD/L, 15 mg BOD_5/L, 8 mg N/L and 1 mg P/L. The treated wastewater is released to a small stream (Tude Å). Several micropollutants in the treated wastewater are exceeding the predicted no-effect concentrations ($PNEC_{Freshwater}$) in the stream. Among these are benzotriazole, diclofenac, tramadol and venlafaxine. Slagelse WWTP has decided to implement full-scale advanced treatment to remove micropollutants and pathogens before 2025.

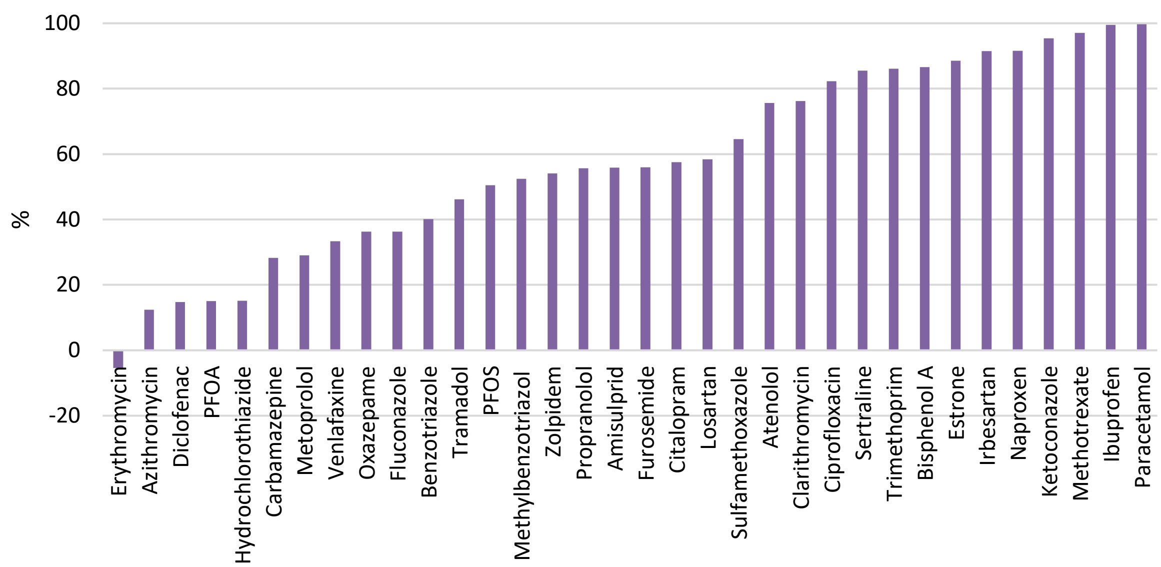

Figure 5. Micropollutant removal efficiency in the conventional WWTP at Slagelse (before introduction of GAC). For details, see Figure 7-5 in the Danish report on Deliverable 4.1 and 4.2.

The removal efficiency of drugs in WWTP in Slagelse is presented in Fig. 5. The negative efficiency was found only for Erythromycin, diclofenac, azithromycin, and hydrochlorothiazide characterized the efficiency removal lower than 20%.

Short description of the pilot plant

In 2019, Slagelse WWTP constructed a large-scale pilot plant to pre-test methods for the future full-scale solution. The objective was to clarify whether a relatively simple post-treatment, based on particle filtration followed by a granular activated carbon (GAC) filter and UV, could reduce the micropollutant concentrations below the effect levels, see process scheme in the Figure 6

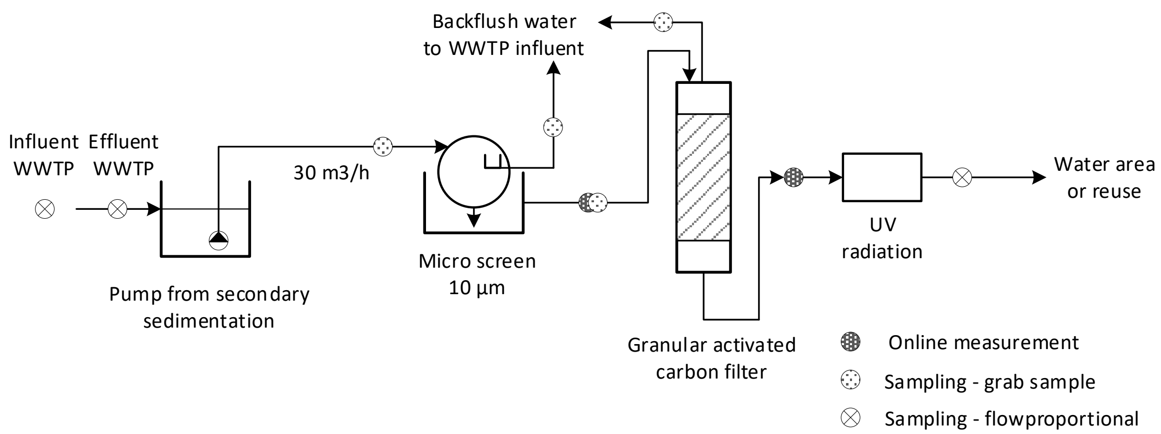

Figure 6. Outline of the pilot plant in Slagelse.

The pilot plant treats approximately 720 m^3/d, which corresponds to 8% of the average dry weather flow into Slagelse WWTP. The wastewater is pumped from the secondary sedimentation tank to the micro screen. The plant consists of a drum filter with a micro screen (10 µm) for SS-removal, followed by a GAC-filter for adsorption of micropollutants and UV-radiation (Ultraaqua A/S) for pathogen destruction. The GAC-filter was filled with reactivated Organosorb 20 from Desotec. The empty bed contact time was 34 min and backwashing was done six times with water from the secondary clarifiers.

Overall pilot results

The pilot was operated during 1.5 years, reaching 14 900 bed volumes. The installed drum filter worked as planned and prevented suspended solids, especially string algae, from reaching the GAC filter.

A total removal rate (from inlet to pilot plant effluent) of organic micropollutants of > 90% was observed after 1.5 years of operation and 14 900 bed volumes, see Figure 7. Removal percentages for 14 critical substances and three Swiss pharmaceuticals (clarithromycin, metoprolol and citalopram) are found in Table 1.

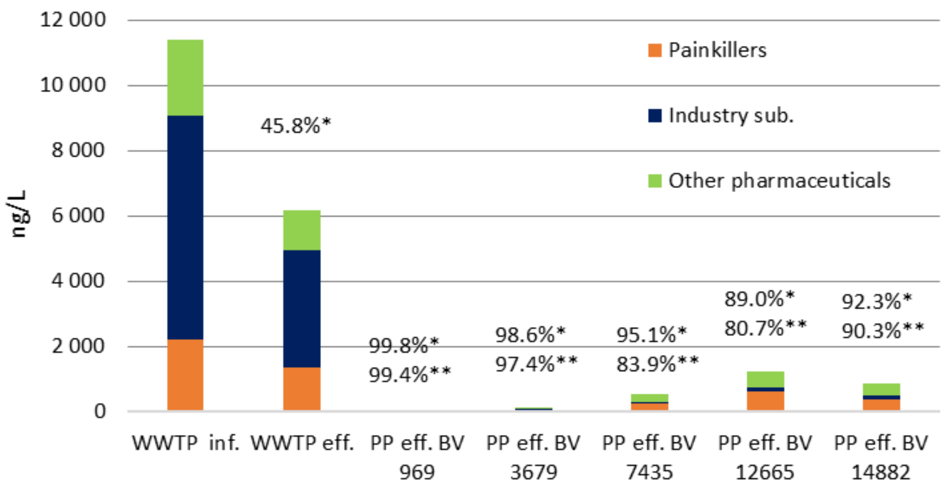

*Figure 7. Sum of concentrations of the 14 critical micropollutants from sampling points in influent and effluent to conventional WWTP and in the effluent from the pilot plant (PP) after a growing number of bed volumes (BV).*Reduction of total concentration relative to WWTP inf. **Reduction relative to WWTP eff.*

Table 1. Pilot plant removal percentages (from effluent conventional WWTP to effluent pilot plant) for 14 critical substances and three Swiss pharmaceuticals (clarithromycin, metoprolol and citalopram). Substances measured above $PNEC_{Freshwater}$ are highlighted.

	Pilot plant removal percentage							
Bed Volumes	969	2,442	4,541	6,026	8,986	10,322	12,665	14,882
PFOS	98	89	64	64	22	34	33	46
Clarithromycin	95	76	49	43	29	31	15	49
Azithromycin	100	95	85	61	35	70	56	75
Bisphenol A	91	82	67	42	21	30	41	77
Diclofenac	99	98	90	88	66	47	55	78
Oxazepame	100	100	96	93	60	34	64	80
Venlafaxine	100	99	98	90	56	41	62	82
Carbamazepine	100	100	98	97	72	49	74	82
Tramadol	100	100	99	96	70	55	69	85
Ciprofloxacin	100	n.d.	100	100	100	75	76	85
Metoprolol	100	100	99	100	84	66	84	92
Citalopram	100	100	100	99	77	74	85	93
Sertraline	100	100	100	100	100	100	100	95
Benzotriazole	100	100	100	100	98	95	98	97
Methylbenzotriazol	98	100	97					97
Estrone	100	100	99	100	85	73	99	98
Propranolol	100	100	100	100	100	90	100	98
Total removal 14 substances	99	95	89	83	65	60	67	82

≥80%

50-80%

20-<50%

<20%

Considering microbial parameters and including the UV-treatment the following could be concluded:

The analysis of microbial parameters showed that total counts, E. coli and enterococcus were reduced to below the Danish drinking water quality criteria in the pilot plant effluent. Antibiotic resistant bacteria (VRE, CPE and CEF) were reduced to below limit of detection. The pilot plant effluent also complies with class A (the tightest requirements) of the EU regulation for water reuse for agricultural irrigation.

The Svedala case

This description (including figures and tables) is based on the national reports (Deliverable 4.1).

Short description of WWTP

Svedala WWTP was built in 1974 and re-constructed in 1996 for additional nitrogen removal. Approximately 12 000 persons are connected as well as a few minor industries. Figure 1 illustrates the process configuration at the plant.

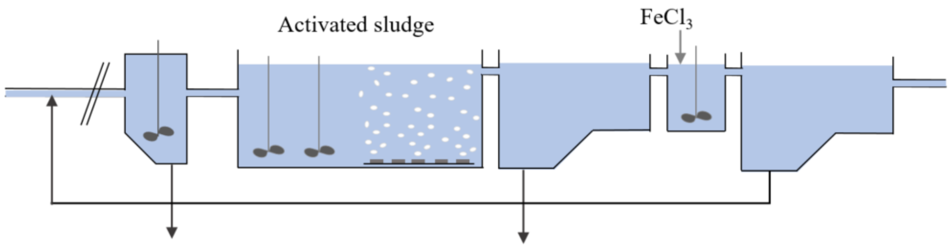

Figure 8. The process configuration at Svedala WWTP.

The process is based on mechanical, biological and chemical treatment. After screening (3 mm) and grit removal in an aerated sand trap, water is directed to an activated sludge process (no primary settling) configured for pre-denitrification with swing zones for adjustment of aeration with respect to variations in loading. After secondary settling follows post-precipitation (iron chloride) and tertiary settling before water is discharged to the recipient Sege å. Waste sludge is dewatered through centrifugation and stabilized by lime addition. The plant is operated with complete (or close to) nitrification and considering the requirements the effluent quality should be well suited for GAC-filtration. Effluent DOC was, on average, 12 mg/L during the test period (2019-2020) and SS below 10 mg/L (6.7 mg/L).

Effluent requirements are: Tot-N: <10 mg/L (yearly basis), Tot-P: <0.3 mg/L (monthly basis), BOD: <10 mg/L (monthly basis)

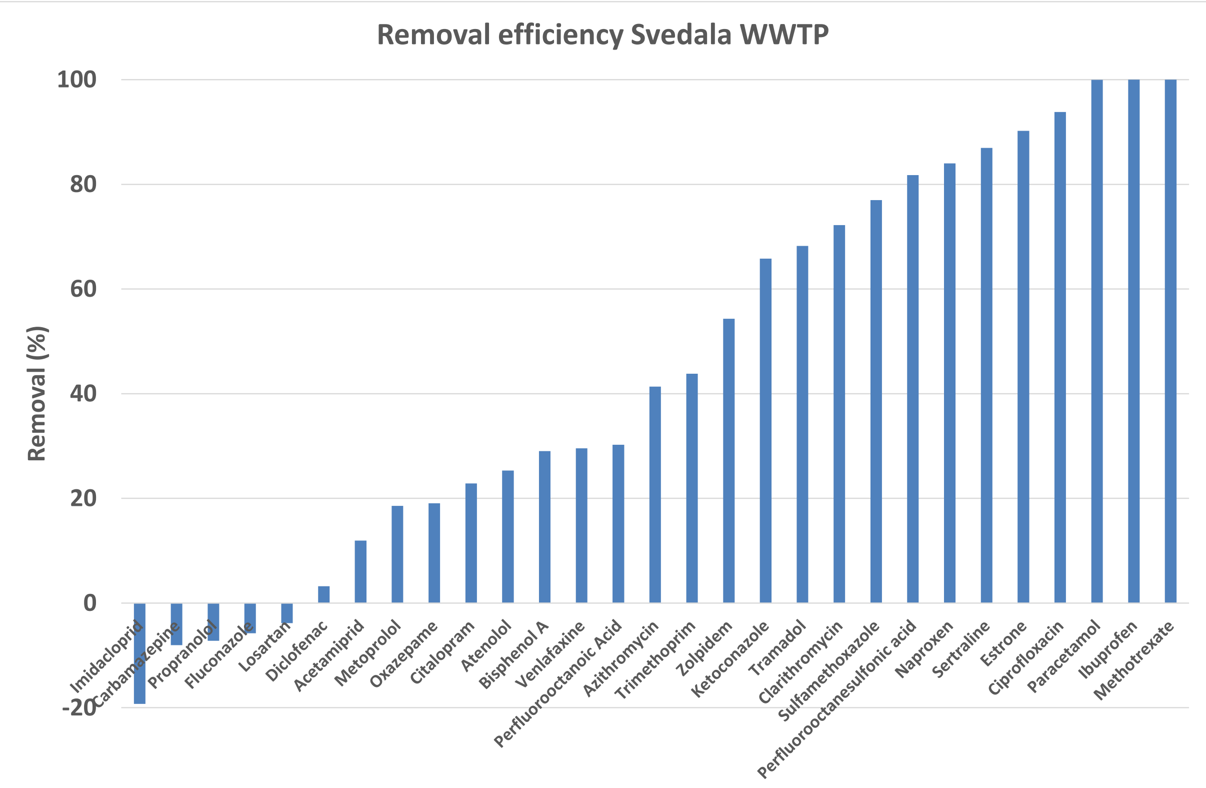

Figure 9. Micropollutants removal at Svedala WWTP.

In Svedala WWTP, five drugs characterized the negative removal efficiency (Fig. 9)

GAC-filtration at Svedala WWTP

GAC filtration was tested on long-term basis on biologically treated wastewater. The empty bed contact time (EBCT) was kept at 10 minutes, which is at the lower end according to literature, often suggesting 20-30 minutes (Fundneider et al., 2021). Higher EBCT was tested showing that removal could be improved for several substances. Figure 3 summarizes removal at 3000 bed volumes.

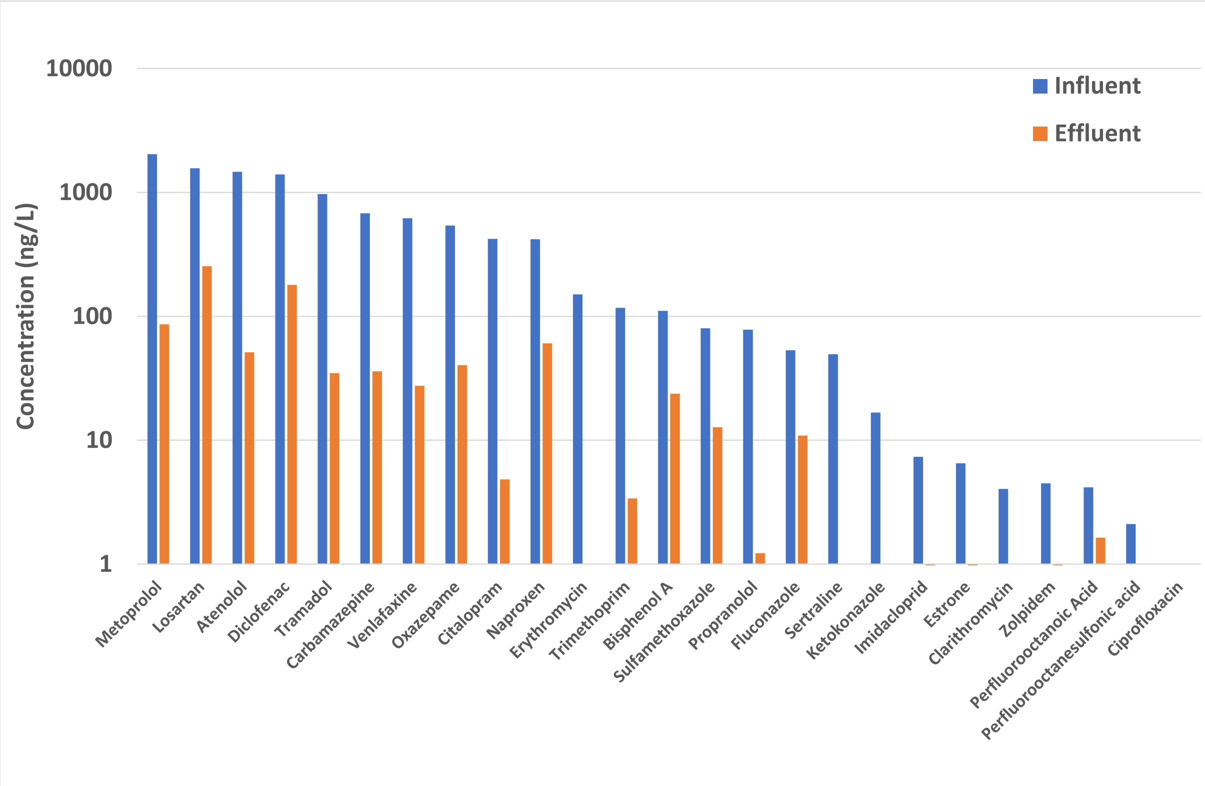

Figure 10. Influent and effluent concentrations to and from the GAC filter (3000 BV) treating biologically treated wastewater.

At this stage, the GAC filter results in high removal corresponding to at least 90% for most substances. Several of the compounds could not be quantified in the effluent from the GAC filter. Table 2 summarizes removal at different bed volumes corresponding to different operational times.

Table 2. Removal of organic micropollutants (%) in GAC filtration at different bed volumes.

	Removal at 3000 BV (%)	**Removal at 8000 BV (%)**	**Removal at 18000 BV (%)**	**Removal at 22600 BV (%)**
Metoprolol	96	97	81	50
Losartan	84	72	42	27
Atenolol	97	97	75	48
Diclofenac	87	74	47	27
Tramadol	96	94	60	37
Carbamazepine	95	91	63	40
Venlafaxine	96	92	58	38
Oxazepame	93	86	60	34
Citalopram	99	98	88	71
Naproxen	86	80	48	25
Erythromycin	100	69	29	-18
Trimethoprim	97	97	91	51
Bisphenol A	79	87	71	35
Sulfamethoxazole	84	60	17	-44
Propranolol	98	98	94	74
Fluconazole	79	65	38	19
Sertraline	100	100	100	100
Ketokonazole	100	100	100	85
Imidacloprid	91	93	65	38
Clarithromycin	100	80	72	-13

For some (biodegradable) substances overall removal will be higher considering also removal prior to the GAC-filter. Sulfamethoxazole is an example of a substance that will show considerably higher removal if biological treatment is taken into account. At 22600 bed volumes removal in the GAC filter is deteriorated for most substances and in some cases the results indicate potential desorption (negative removal). The type of effluent requirements (specific effluent concentrations or percentage removal) and the corresponding time constraints (requirements based on for example monthly or yearly averages) will govern when GAC media should be replaced or regenerated. Based on the carefully selected indicator substances in the LESS IS MORE project it has been demonstrated that advanced treatment based on GAC filtration could be a viable solution to remove not only pharmaceutical residues but also other organic micropollutants.

Concept proposal for Slupsk

Key conditions to consider

Slupsk WWTP has similar capacity to Slagelse WWTP. The key difference is using the biological P-removal and higher organic matter concentration in effluent.

Slagelse and Svedala cases have demonstrated an efficient CECs removal using GAC filter. Svedala pilot test has shown than using smaller EBCT (10 min) can lower the removal efficiency. EBCT of 30 min should be recommended as common parameter.

Technical data

Pilot plant proposal for Slupsk is based on Slagelse pilot plant presented in Fig. 11.

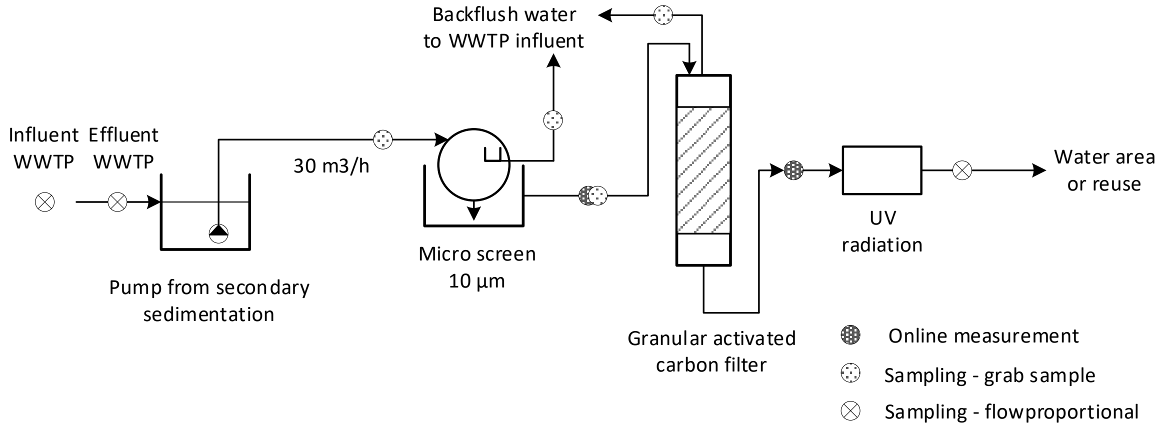

Figure 11. Outline of the pilot plant for Slupsk (based on Slagelse pilot plant)

Preliminary design of the plant based on the Danish pilot is found in Table 3.

Table 3. Geometrical dimensions, hydraulic loading and GAC properties of the Mobicon 100 filter unit.

Mobicon 100 Design data	Properties	Unit
Design Flow	30.0	m^3/h
Filtration velocity	6.1	$m^3/m^2 \cdot h$
Empty Bed Volume	17.0	m^3
Empty Bed Contact Time	34.00	min
Cross sectional area	4.9	m^2
Bed height	3.5	m
Mass of Carbon	7480	kg
Bulk density of Carbon	480	kg/m^3
Particle density of Carbon	795	kg/m^3
Bed porosity	0.45	-
Organosorb 20 Particle Size	1.7 (0.42-2.8)	mm

Estimated cost

Cost analysis was based on Slagelse case basing on the final investment cost concerning some unexpected conditions and comparing the costs of materials, devices and equipment. The investment cost for Slupsk pilot plant that should be considered.is c.a. 200 000 EUR.

Operational cost of pilot plant is based on energy and GAC consumption. Average energy consumption is 0,24kWh/m^3 and it will be similar in Slupsk case. For Slagelse case 30000 BV is a basic lifetime of GAC. Due to higher organics concentration expressed as a DOC (about 15 mgC/L), 20 000 BV should be considered as a GAC lifetime for Slupsk pilot plant and GAC usage is c.a. 15 mg/dm3. Total operational cost for pilot plant in Polish condition will be c.a. 16 000 EUR/year.

Alternative treatment

Direct Membrane Filtration as an effluent polishing process has been considered. This concept was rejected due to a risk of recycled concentrate effect on the quality of compost produced in Slupsk WWTP.

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