Advanced wastewater treatment for API elimination at Kohila WWTP

Feasibility study

GoA2.2: Applying recommendations for planning of API removal and plant optimization

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Introduction

The aim of this study is to implement the "Guideline for advanced API removal" [1] at the wastewater treatment plant (WWTP) in Kohila, Estonia. The study was part of the Clear Waters from Pharmaceuticals 2 (CWPharma 2) project and funded by the EU's Interreg Baltic Sea Region Programme. It analyses the current status of Kohila WWTP and compares various technological solutions for the removal of active pharmaceutical ingredients (APIs). The main focus is on a general analysis of technological solutions for API removal, identifying potential barriers, and comparing the capital (CAPEX) and operating expenses (OPEX). A simplified process design is prepared to compile a comparison of, for example, the amount of activated carbon, ozone dose, etc. needed.

The basic concept of the guideline is based on the following steps:

- WWTP fitness check, which includes a brief check of current situation and should define the overall targets for API reduction and evaluate different scenarios (using different technologies);
- More detail analysis about the current situation: description of the catchment area (defining relevant hotspots like hospitals etc), overview of flows and concentrations of relevant parameters (DOC, COD, TSS, nitrite, bromide etc.);
- API monitoring campaign (when there is no existing data, then it is important to get influent and effluent API data);
- State of art/knowledge of AWT (advanced wastewater treatment). Short description of available AWT technologies;
- Preliminary design of AWT with basic cost estimations;
- Overall evaluation is the conclusion part, where the most suitable AWT technology for the specific WWTP is described.

WWTP

Kohila WWTP is located in Estonia, Rapla County, Kohila municipality. The population of the settlement is about 3200. The location is shown in Figure 1. There are a number of industrial enterprises in Kohila which are mainly active in the wood industry. There are also several schools, kindergartens, nursing homes and some food industry companies in the settlement.

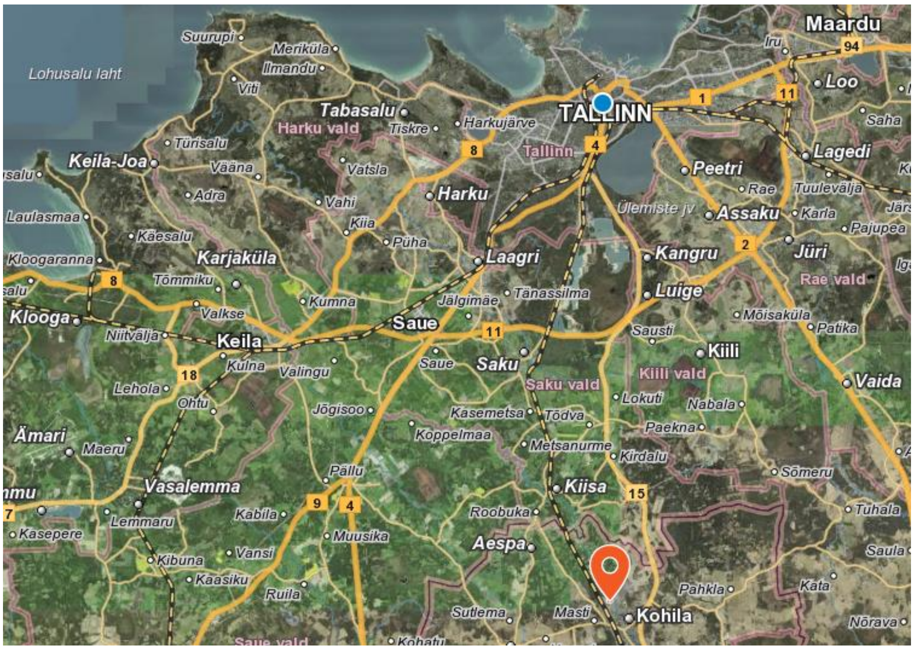

Figure 1: Map showing the location of Kohila (Geoportal of the Land Board).

WWTP process

Kohila WWTP is using a sequencing batch system (SBR) technology for the biological treatment of the wastewater. The WWTP is designed for a dry weather flow of 880 m^3/d and a maximum hydraulic capacity of 1400 m^3/d. A technical scheme of the wastewater treatment process is shown in Figure 2. During the first treatment stage, larger particles and grit that would damage the operation of the subsequent processes, are removed. Particles often do not settle and would therefore end up in the receiving waters or get incorporated into the sludge. Grit is abrasive and would wear out the pumps and, as a result of settling, reduce the volume of the equalization basin and the SBR. Following the mechanical treatment, the wastewater is balanced in a balancing tank with a maximum capacity of 500 m^3.

In the next step, a biological treatment is carried out where the organic substance is largely incorporated into biomass and removed as excess sludge. Nitrification and denitrification are used for nitrogen removal where, under aerobic conditions, ammonium is oxidised to nitrate and under anoxic conditions, nitrate is reduced to gaseous nitrogen. Denitrification requires the presence of a sufficient amount of readily degradable organic matter (BOD_7). For phosphorus removal, both biological and chemical treatment are used. During biological phosphorus removal, anaerobic conditions are created in the SBR, releasing phosphate accumulated in the cells of the micro-organisms in order to make room for a readily usable organic matter. After that, aerobic conditions are created where organic matter in cells is rapidly consumed and micro-organisms are forced to re-collect phosphate in their cells for energy. As aerobic and anaerobic conditions continue to change, bacteria that are capable of binding 4-6% (of total BOD_7) more phosphorus than most common micro-organisms that break down the organic matter (otherwise on average 1-2% of the total BOD_7), begin to grow in the activated sludge environment. For the further phosphorus removal, $Fe_2(SO_4)_3$ or PIX 115 is dosed to SBR, where it reacts with dissolved phosphate and forms insoluble compounds that are removed with excess sludge. The effluent is discharged directly to the receiving water body, without further balancing. The sludge treatment consists of two static sludge thickeners where approximately 2.1% dry matter content is achieved, and after that the excess sludge is dewatered with a “screw press”, until a dry matter content of approximately 19% is reached. The sludge is then composted and used mostly for greenery.

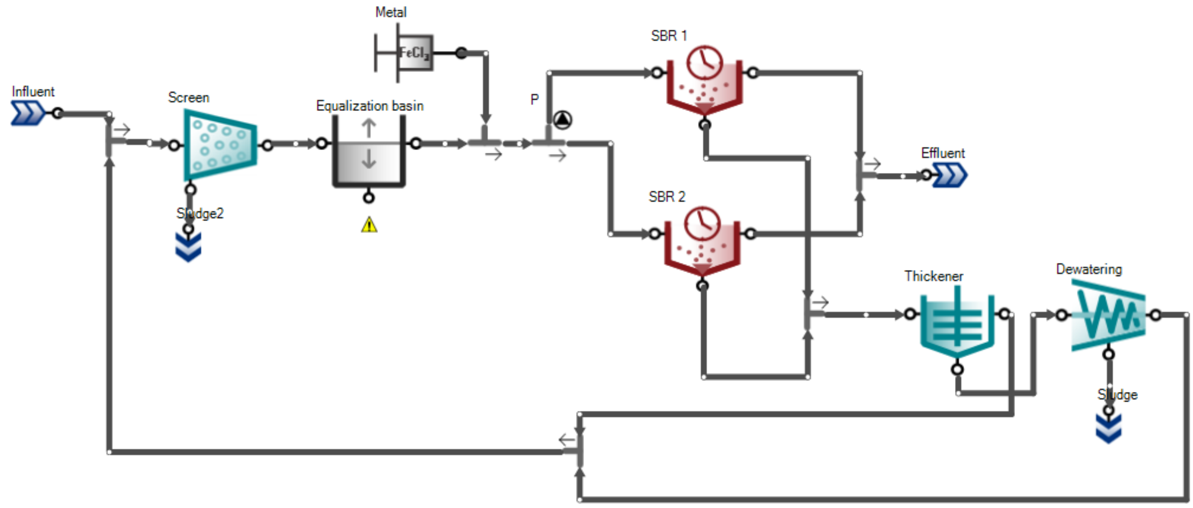

Figure 2: Technical scheme of Kohila WWTP.

Flows and water quality parameters of WWTP

Figure 3 shows the incoming wastewater flow of Kohila WWTP in 2020-2021. The figure reveals that the flow varied strongly over the year. The average flow was 554 m^3/d and the 85^{th} percentile value was 679 m^3/d. The minimum daily flow for this period was 122 m^3/d and the maximum flow was 1 703 m^3/d (Table 1).

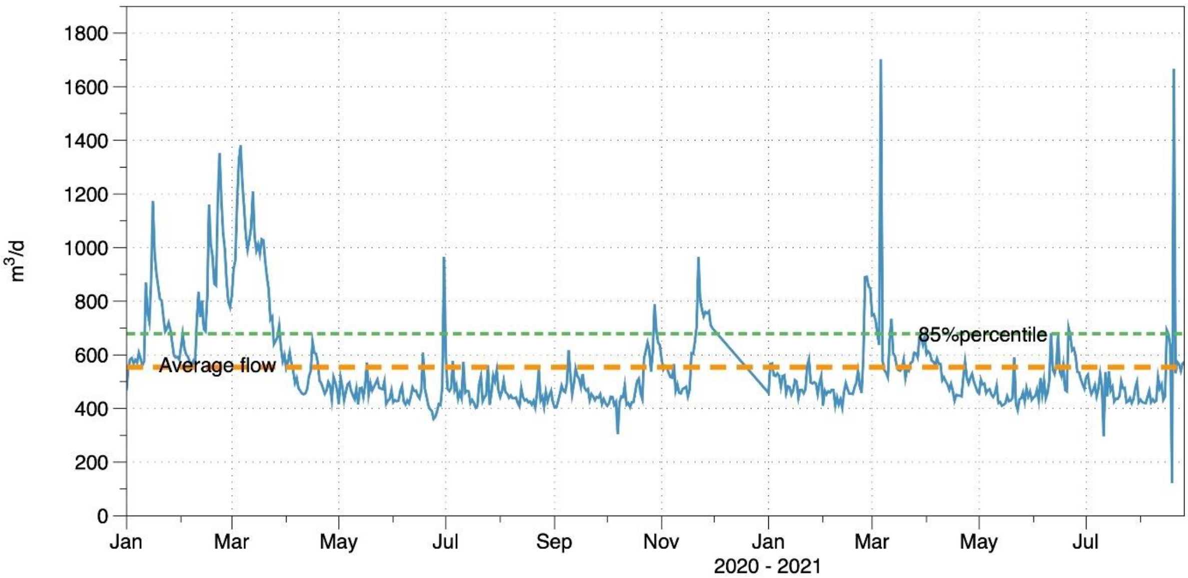

Figure 3: Incoming wastewater flow at Kohila WWTP in 2020-2021.

Compared to the design data, the average WWTP’s hydraulic loading rate is ca 60%. However, as the incoming hourly flow may fluctuate due to the melting of snow and precipitation in large ranges, there are certainly days where the hydraulic loading rate exceeds the maximum design capacity.

Table 1: Summary table for hydraulic loading rate in 2020-2021.

	Incoming flow (m^3/d)
Average	554
Min	122
Max	1 703
85%	679

WWTP influent and effluent pollution load analysis

Table 2 show the concentrations of selected water quality parameters at the influent of Kohila WWTP. Since the flow is significantly lower than the WWTP was designed for, the best way to assess the incoming loads to the WWTP is to compare the daily loads to the design values.

Table 2: Concentrations of selected water quality parameters at the influent of Kohila WWTP in 2020-2021.

	BOD_7 (mg/l)	**COD (mg/l)**	**TSS (mg/l)**	**TN (mg/l)**	**TP (mg/l)**
Average	553	1 524	779	109	26,6
85%	695	2 525	1 425	145	33.8

Table 3 reveals that for BOD_7, the average load in recent years has been 12% lower than the WWTP was designed for. A slight overload is observed in the case of TSS as the design load is 350 kgTSS/d. The excess sludge removal is directly affected by the TSS, the higher the amount of TSS, the higher the amount of excess sludge removal required compared to the designed volumes. In the case of nitrogen, the WWTP operates at an average of approximately 14% below the designed load, i.e. when taking additional wastewater (for example from industry), the pollution load of nitrogen must be monitored. The problematic parameter is phosphorus because the removal technology was designed for a load of 13 kgTP/d, but the average phosphorus load is approximately 15 kgTP/d. In addition, the limit value for phosphorus has changed from 1.5 mgTP/l to 1 mgTP/l after the plant was designed.

Table 3: Loads of selected water quality parameters at the influent of Kohila WWTP in 2020-2021.

	BOD_7 (kg/d)	**COD (kg/d)**	**TSS (kg/d)**	**TN (kg/d)**	**TP (kg/d)**	**p.e.**
Average	306	844	432	60	15	5 107
85%	472	1 714	968	98	23	7 865
Design	350	-	350	70	13	6 567

Figure 4 shows the average influent and effluent concentrations of Kohila WWTP. The figure reveals that the treatment process is capable for efficient wastewater treatment, but the high variability of certain parameters poses a challenge. The biggest fluctuations can be observed for TSS and COD with a standard deviation of 771 mg/l and 513 mg/l in the influent, respectively.

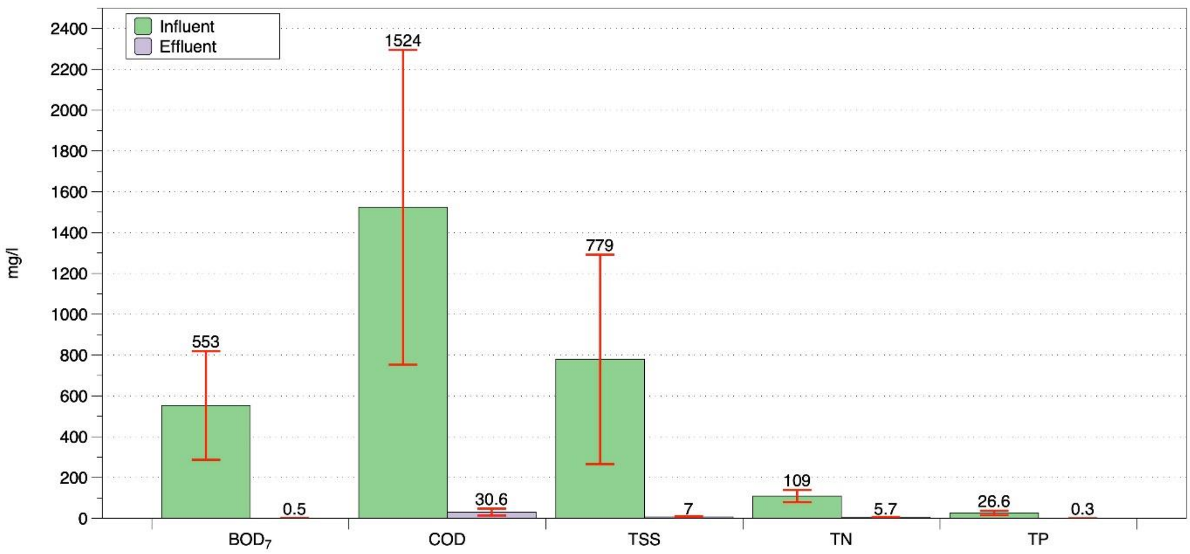

Figure 4: Comparison of influent and effluent concentrations of Kohila WWTP in 2020-2021.

Figure 5 shows the API concentrations in the influent and effluent of Kohila WWTP. Results are based on two sampling campaigns that have been conducted in 2021. The samples where collected as grab samples from the equation basin and effluent of the SBR. The figure reveals that the wastewater in Kohila contains at least 4 APIs with concentrations above 5 µg/l: diclofenac, gabapentin, ibuprofen, and iohexol. Diclofenac, which is very stable in the environment and not readily biodegradable, can be pointed out as particularly problematic. According to the report "Pharmaceuticals in the Baltic Sea Region - emissions, consumption and environmental risks [2]" prepared in the framework of the CWPharma project, the PNEC (predicted no-effect concentration) of some APIs in Figure 5 are as follows:

- diclofenac 0.085 µg/l;
- gabapentin 100 µg/l;
- ibuprofen 0.00012 µg/l;
- sulfamethoxazole 0.0438 µg/l;
- carbamazepine 1.28 µg/l;
- valsartan 125 µg/l;
- iohexol – no data available.

For other APIs and their PNEC, please see the report referred to above.

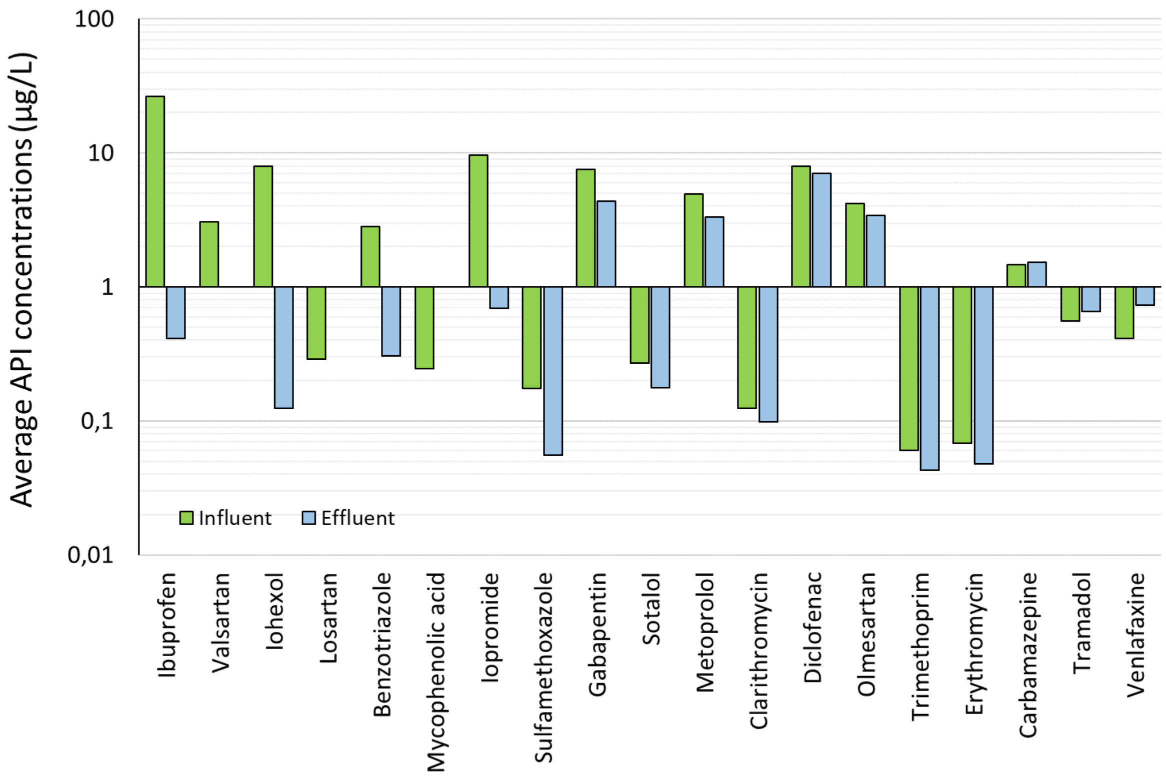

Figure 5: API concentrations in the influent and effluent of Kohila WWTP based on two sampling campaigns.

In other words, based on the PNEC and actual measured concentrations above, Kohila should mainly apply technology to remove diclofenac, sulfamethoxazole, and carbamazepine. However, some of the APIs are also removed during the wastewater treatment process, where they accumulate in excess sludge or are biodegraded. For example, based on the samples taken in this study, the content of the following APIs decreased by more than 98%:

- ibuprofen;
- valsartan;
- iohexol;
- losartan;
- mycophenolic acid.

The results revealed that a further removal of APIs would be necessary to remove diclofenac, which was only 11% reduced. Also, sulfamethoxazole in the effluent exceeds its PNEC value, though it decreased by 68.5% during the wastewater treatment process, but still exceeds the PNEC value. The concentration of carbamazepine is the same in the influent and effluent and exceeds the PNEC value.

Although the flow rate of Kohila WWTP is extremely low and API concentration's showing no direct hazard to wildlife, a feasibility study is carried out to assess the possibility to decrease API overall load to the receiving water body and the CAPEX and OPEX at Kohila WWTP.

Overview of API elimination technologies

Today, a number of promising technologies are known for the removal of active pharmaceutical ingredients (API). Scientific studies and pilot studies have shown that ozonation and adsorption with activated carbon, or combination of both, can be considered as the most promising technologies.

Table 14 outlines barriers for the implementation of ozonation and activated carbon (PAC, GAC) processes along with possible synergies with the removal of other pollutants (e.g. phosphorus, heavy metals, etc.). For example, implementation of a PAC process at which the PAC ends up in the activated sludge process is excluded unless the excess sludge is incinerated. Otherwise, the API loaded PAC would also end up in the environment (e.g. disposal of the dried excess sludge in agriculture or landscaping), but only on another way. Likewise, bromate formation by the ozonation should be careful checked if the content of bromide exceeds 0.150 mg/l.

Table 4: Comparison of various API removal technologies and possible synergies in removing other pollutants. [1]

Category	Threshold	PAC	GAC	O3
Sludge disposal	Not incinerated	-	o	o
Bromide	> 0.150 mg/l	o	o	-
High influence of industrial WWT	> 30%	Pilot/lab studies should be conducted		
Current WWT process		Filtration is helpful for post-treatment	Filtration is helpful for post-treatment	Biological WWT step is helpful for post-treatment
Future water quality improvement plans	Reduction of C/N/P concentrations in WWTP effluent	C: + N: o P: + with coagulation, Heavy metals	C: + N: o P: + with coagulation Heavy metals	C: + N: - (high oxygen levels hinder post-denitrification processes) P: + with coagulation and suitable post-treatment (e.g. filter)

Ozonation

We already have a long history of using ozonation in drinking water treatment, where it is mainly applied to reduce organic matter content (for example, in surface waters) and for disinfection purposes. For APIs, ozone changes their chemical structure. At best, the product is a substance that is safe for the environment or degraded in the environment. At worst, an intermediate product (transformation or oxidation by-product) is produced, which can pose a greater risk to the environment than the API itself. Therefore, correct ozone dosing and, in certain cases, the use of activated carbon filter is necessary, to reduce intermediate product concentrations. The scheme of a typical ozonation plant is shown in Figure 6. For more details on ozonation, see the "Guideline for advanced API removal" [1] by CWPharma, beginning on page 7.

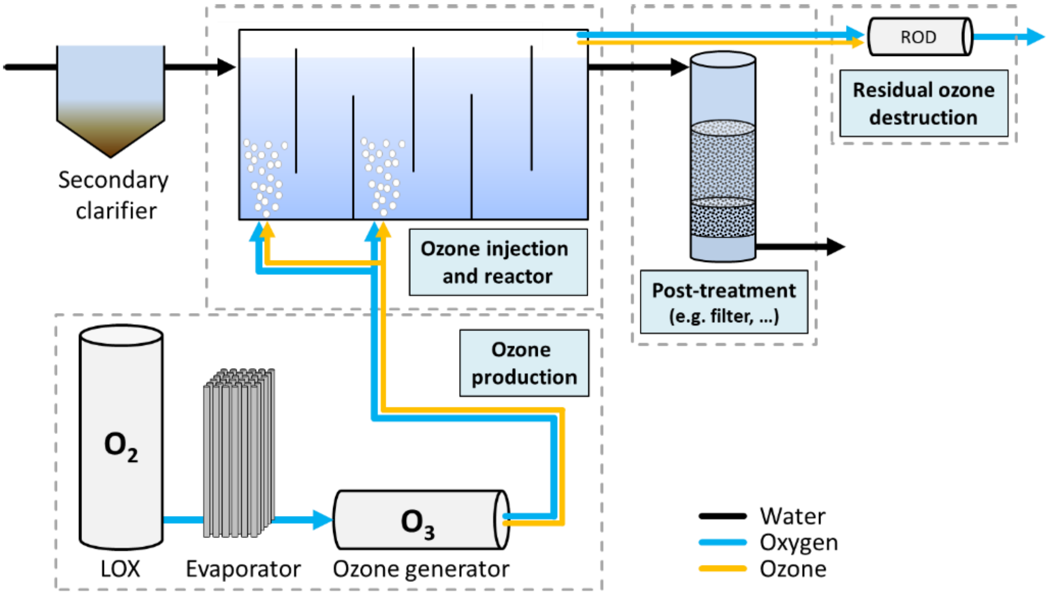

Figure 6: Scheme of a full-scale ozonation plant consisting of an ozone production unit, an ozone injection and reactor, an off-gas treatment, and post-treatment.[1]

The disadvantage of this technological solution is that we only remove organic substances and the concentrations of, for example, phosphorus, heavy metals etc. do not decrease, unless a post-treatment, such as sand filter, is applied.

For ozonation it is mandatory to use a post-treatment, because some by-products can have ecotoxicological potential. To reduce this potential harmful effect ozonation must be followed by a post-treatment, either biological or adsorptive. For example MBBR, sand-filter, biological activated carbon or only activated carbon (GAC).

Powdered activated carbon

Powdered activated carbon (PAC) is, in certain cases, also used to remove various hazardous substances. The PAC particle size is usually 0.005-0.1 mm, which is why its specific surface is larger than that of GAC. The main difference is that PAC can't be reused, but GAC can be regenerated. For example, PAC can be dosed directly into the activated sludge process (Figure 7, solution A) where it adsorbs various organic and inorganic compounds such as heavy metals, API, etc. PAC loaded with hazardous substances are removed with excess sludge. The advantage of this solution is that the technological solution is relatively simple and does not require large investments. However, as the level of hazardous substances in excess sludge increases, the sludge usually has to be incinerated. In the case of solutions B and C illustrated in Figure 7, PAC is dosed after biological treatment and therefore a separate treatment stage with PAC removal is required. In most full-scale plants the PAC is rejected to the CAS system and it will increase the harmful substances concentration in excess sludge. Other possibility is to treat the excess sludge from the PAC treatment step separately. The advantage is that the excess sludge does not get contaminated with additional hazardous substances, but the disadvantage is the higher CAPEX of setting up an additional treatment stage.

As adsorption is a physical process, it depends on the following factors for both PAC and GAC:

- the concentration of the adsorbed substance;
- the dose and quantity of activated carbon;
- adsorption residence time;
- water temperature and pH.

When using PAC, removing it will be an additional challenge because, since the particles are very small, it is often necessary to use, in particular for solutions B and C, auxiliary chemicals that coagulate the fine PAC particles into bigger ones that can be removed by a filter. If PAC is used and e.g. solutions B and C are applied, it can be assumed that the phosphorus load to the receiving waters will also decrease.

For more details on PAC, see the "Guideline for advanced API removal" [1] by CWPharma, beginning on page 15.

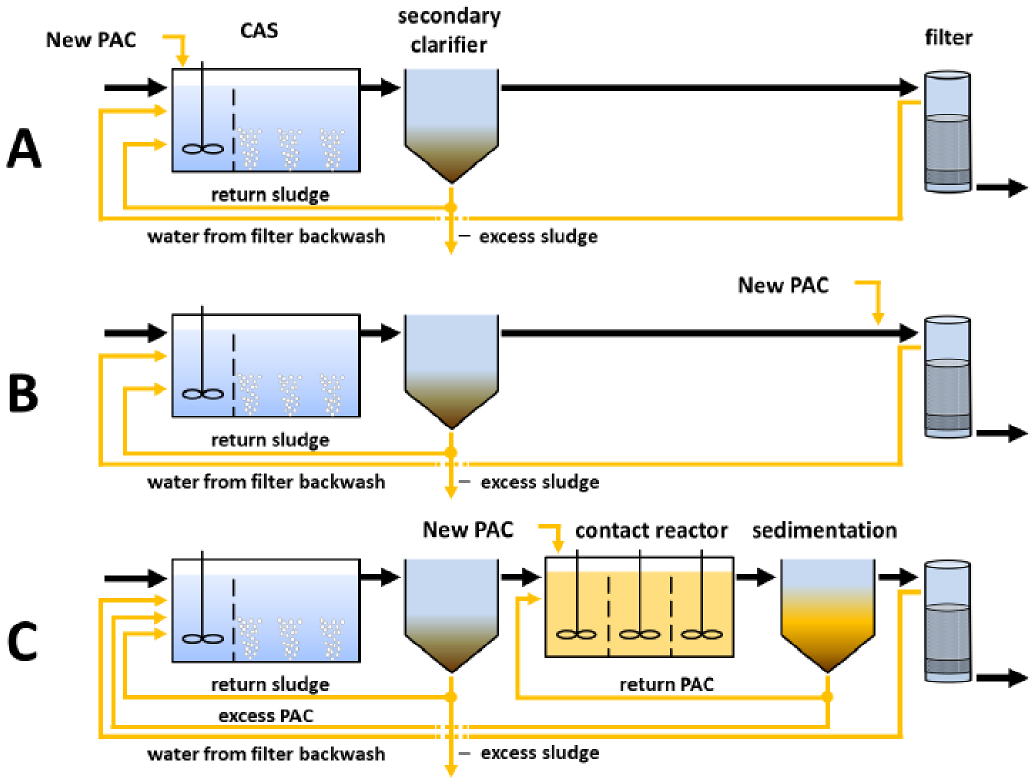

Figure 7: Schematic overview of various PAC processes that have been applied at full-scale plants: A) simultaneous PAC dosage, B) PAC dosage prior to a filter, and C) separate PAC contact reactor ("Ulmer process"). [1]

Granular activated carbon

In the case of the granular activated carbon (GAC) process, a separate activated carbon filter will be set up for post-treatment, where the size of the GAC particles is usually between 0.5 and 2.5 mm. The advantage of GAC is that it can also be used for existing sand filters by replacing parts of the existing filter material with GAC for additional treatment efficiency. In certain cases, it is necessary to modify the backwash system so that the lighter activated carbon is not carried out.

During the GAC process, both various organic pollutants, including API, and particulate phosphorus (but preferred is to use a sand filter as pre-filtration step or sand layer below the GAC), are removed. It is possible to further improve phosphorus removal by adding coagulant. The content of heavy metals, which can be easily removed by adsorption (depending on their characteristics), is also reduced.

The scheme of a GAC filtration process is shown in Figure 8. For more details on GAC, see the "Guideline for advanced API removal" [1] by CWPharma, beginning on page 19.

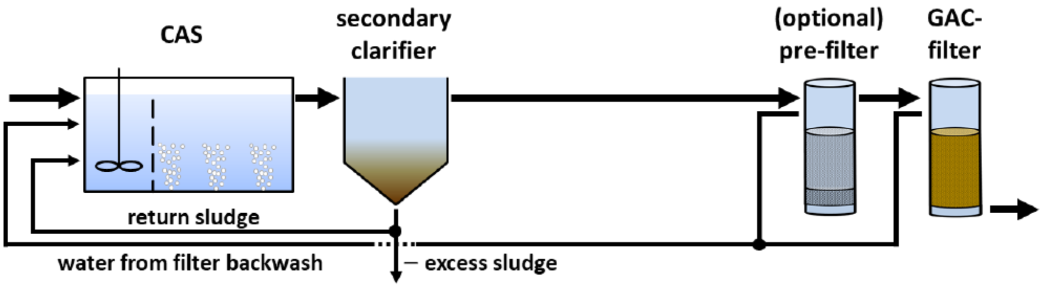

Figure 8: Scheme of a full-scale GAC process. [1]

Preliminary design of AWT technology

Ambitions of API elimination technology

Although today there are no requirements for the removal of APIs, several countries have taken the view that large WWTPs could still do so to avoid the potential adverse effects of APIs and their metabolites. While previous research has rather focused on WWTPs larger than 250,000 p.e., it is still interesting to identify whether the application of post-treatment technologies on a small WWTP that uses SBR technology is technologically and economically possible, while also assessing potential synergies for the removal of other pollutants, such as phosphorus and heavy metals.

Based on CWPharma's Guideline for advanced API removal" [1], the first step is to set the goals that the respective technology has to meet. In the case of Kohila WWTP, these would include:

- 80% API removal at the yearly average results;
- further 30% reduction of phosphorus load at the daily average flow rate;
- reducing the load of heavy metals[1].

A further challenge for Kohila WWTP is the lack of a post-balancing tank. Without that tank, it is difficult to build an additional filtration stage because the hydraulic load to the filter would be very uneven.

Boundary conditions for the scenario analysis

More detailed technological data, including the targets to be used in the feasibility study, are outlined here.

- The preliminary design is based on an average flow rate of 554 m^3/d, i.e. our aim is to ensure efficient removal of APIs, heavy metals and further phosphorus removal at the average flow rate. As it is a SBR, the AWT mainly dependent on the size of the post-balancing tank.
- The required volume of the post-balancing tank was determine to be ca 260 m^3, which would allow a certain time for maintenance, for example, if the filtration equipment is to be maintained or the filter is currently in backwash. Thus, two SBR lines would decant into the post-balancing tank in every 6 h approximately 138.5 m^3 of wastewater, making the hourly flow to be about 23 m^3/h, which is also the basis for the design of the API removal technology. The post-balancing tank is required, whichever the technological solution, and is therefore not addressed in the further analysis.

Evaluated scenarios

The focus in this study is on two technologies: ozonation and GAC filtration. Implementation for a PAC process was not considered as there is no sludge incineration facility in Estonia today. Additionally, application of a PAC process that is not adding PAC directly into the biology (solutions B and C, Figure 7) was assessed to be impractical, considering the size of Kohila

[1] In Estonia, requirements for heavy metals applied to WWTPs are the same as those applied to surface waters, i.e. often more stringent than those laid down for drinking water, and as a result, for example, the use of coagulants for phosphorus removal may cause problems in the achievement of certain limits, such as 50 µg/l for Zn

WWTP. However, if only ozone is used, we will only be able to achieve one of the targets above, i.e. API removal, as the removal of phosphorus and heavy metals will not be affected unless post-filtration is applied. In the second scenario, the GAC filter is dimensioned, which adsorbs the APIs and by adding, for example, a pre-filtration with sand, it is possible to perform additional phosphorus coagulation, i.e. phosphorus removal.

Preliminary design for ozonation stage at Kohila WWTP

As already pointed out above, ozone only removes organic pollutants, so no reduction in phosphorus load is expected. It should also be pointed out, as a risk with ozone, that high concentrations of bromide are often present in the coastal areas of the Baltic Sea region, which, when reacting with ozone, forms bromate, which is carcinogenic. During the sampling campaign carried out in the framework of CWPharma 2, the content of bromide in the wastewater from six Estonian WWTPs was often above the recommended concentration of 0.15 mg/L. The results are reflected in more detail in "WWTP fitness check for tertiary treatment"[3]. In Figure 9, the red dotted line represents a limit of 0.150 mg/l.

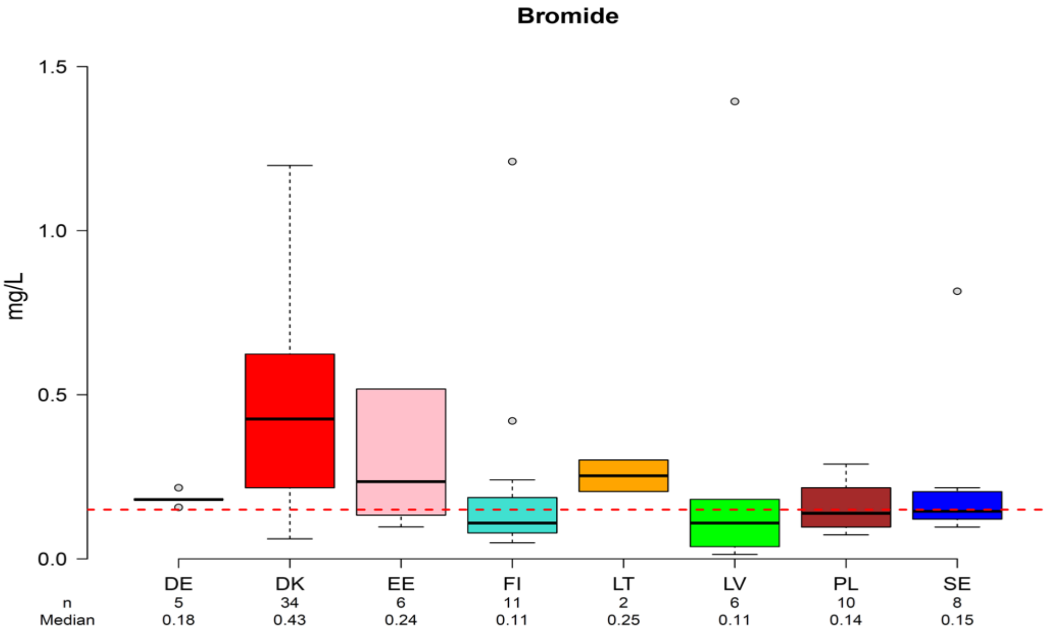

Figure 9: Bromide in analyzed samples. Red line indicates a bromide concentration of 0.15 mg/L. [3]

The dimensioning of the ozonation stage is based on the following data, as shown in Table 5.

Br is an important parameter, which could affect the treatment process, but there are some more relevant water quality parameters like DOC, COD, NO2, TSS, pH, dissolved oxygen. You will find further information about the effect of this parameters on the ozonation in "Guideline for advanced API removal" [1].

In the following, a preliminary design for the ozonation stage indicating the required ozone dose, dimensions of the contact reactor, etc. is prepared. CAPEX and OPEX along with the GAC filter are then compared in a separate chapter. Finally, the main conclusions/recommendations are presented in the chapter summary.

Table 5: Basic design parameters for the ozonation stage at Kohila WWTP.

Scenario description		
Ozonation for the average flow rate		
Q_{min}	11.0	m^3/h
Q_{avg}	23.1	m^3/h
Q_{design}	23.1	m^3/h
$V_{annual,treated}$	202 210	m^3/a
h_{lift}	4	m
C_{DOC}	10.9	mg/L
C_{NO2}	0.35	mg-N/l
Setpoints for ozone production	**Values**	**Units**
$D_{DOC,set}$	0.7	$mgO_3/mgDOC$
$Price_{LOX}$	0.14	€/kgLOX
Default parameters		
SOD	10	kgO_2/kgO_3
$Price_{energy}$	0.12	€/kWh
SEC_{O3}	11.5	kWh/kgO3
SEC_{lift}	5	$W/(m^3*m)$
$C_{O3,productgas}$	148	$gO3/Nm^3$
Gas transfer efficiency	90%	-

Table 6: Operating parameters of the ozonation stage.

Ozone production	**Unit**	**Min**	**Avg**	**Max**
D_{set}	mgO_3/L		8.9	
$m_{O3,production}$	kgO_3/h	0.11	0.23	0.23
$m_{O3,annual}$	kgO_3/a		1 989	
Oxygen supply	**Unit**	**Min**	**Avg**	**Max**
$Q_{gas,min}$	Nm^3/h	0.7		1.5
m_{O2}	kgO_2/h	1.1	2.3	2.3
$m_{O2,annual}$	kgO_2/a		19 885	

Table 7: Technological parameters of the required ozonation stage.

Ozone reactor	**Unit**	**Min**	**Avg**	**Max**
HRT	min	20	20.8	43.6
Reactor depth	m	4		
$V_{OzoneReactor}$	m^3	8		
$A_{OzoneReactor}$	m^2	2		

The technological scheme of the respective technology is shown in Figure 6. For ozonation it is mandatory to use a post-treatment to reduce potential ecotoxicological risks from the ozonation by-products. For Kohila is suitable a MBBR or filter with a GAC layer which gives extra benefits like further phosphorous removal, heavy metals removal etc.

Preliminary design for GAC filter at Kohila WWTP

As already pointed out earlier, the GAC filter is an effective technology for the removal of various hazardous substances, including APIs, heavy metals and, in the case of certain modifications, phosphorus removal. When hazardous substances are adsorbed to the GAC and the corresponding material needs to be changed periodically, then for phosphorus removal further coagulation and flotation is essential. The precipitation obtained is already removed by physical filtration, preferably in the additional sand filter prior to the GAC filter. The technological scheme for the application of the technology is shown in Figure 8 above.

The most important parameters for GAC filter design are [1]:
- EBCT (empty bed contact time): average time the water flow needs to pass through the (empty) filter bed volume, which is defined by filter surface area and height;
- Bed volume: represents the filter runtime, which is equal to cumulated water treated divided with GAC volume in the filter. This normalised filter runtime can be used to compare different GAC filters.

Table 8: Basic design parameters for the GAC filtration at Kohila WWTP (1/2).

GAC consumption	Unit	Avg	Min	Max
Annual bed volumes treated	$m^3/m^3.a$	21 024		
Change frequency (setpoint)	BV	25 000	20 000	30 000
Years until change of GAC needed	a	1.2	1.0	1.4
Annual GAC consumption	m^3 GAC/a	8	10	7
GAC density (after flushing)	t/m^3	0.26		

Table 9: Basic design parameters for the GAC filtration at Kohila WWTP (2/2).

Filter	Unit	Avg	Min	Max
EBCT	min	25	25	52
V_{GAC}	m^3		10	
v_{filter}	m/h		5	
A_{filter}	m^2		5	
h_{GAC}	m		2.1	
h_{sand}	m		0.6	
H_{filter}	m		3.7	
$h_{supernatend}$	m		0.7	
$h_{waterlevel}$	m		3.4	
Filter cells	pcs		3	
$A_{filter,cell}$	m^2		1.5	

Overall evaluation

Ozonation

Above, the preliminary design of two different technologies, ozonation and GAC filtration, was developed. In order to better compare these two solutions, the CAPEX and OPEX for their implementation are outlined here. The costs are based on Estonian electricity prices and on different price offers from construction companies. Equipment prices are estimations based on the expert's previous projects.

Table 10: CAPEX and OPEX of setting up the ozonation stage at Kohila WWTP.

CAPEX, of which	€	a	k€/a
construction	150 000	30	5.0
post-balancing tank	150 000	30	5.0
equipment	50 000	15	3.3
ICE	20 000	10	2.0
additional costs	44 000	30	1.5
a) biological post-treatment (MBBR) or	150 000	30	5.0
b) sand-filter with GAC layer	*250 000*	*30*	*8.3*
Total CAPEX	564 000		**21.8**
OPEX, of which			k€/a
- material			2.8
- electricity			5.3
- staff			9.9
- maintenance			2.3
Total OPEX			**20**

Table 10 reveals that the cost of the investment in the ozonation technology would be approximately EUR 564 000 and the annual operating costs would be approximately 20 000 EUR. In the calculation as post-treatment MBBR was used, because the sand-filter is already covered in GAC filter option. The depreciation of the investment would be approximately EUR 21 800 per year. In total, additional costs would sum up to annual costs of about EUR 42 000, which would increase the specific treatment costs by about EUR 8.2 per p.e..

However, in view of the overall targets, ozonation is not considered to the best solution for Kohila WWTP, as no phosphorous removal can be achieved. In addition, the following challenges need to be taken into account when implementing ozonation in Estonia:

- during winter there are often problems with nitrogen removal, such as inefficient nitrification which significantly increases the required ozone dose, due to expected higher nitrite concentrations;
- earlier studies have shown that bromide concentrations in drinking water are higher than the recommended 0.15 mg/L in many regions. Unfortunately it was not checked for Kohila WWTP;

- Estonian energy production has a high environmental footprint, which is why energy efficient technologies should be used.

GAC filtration

Table 11 shows the cost of setting up and operating the GAC filter. The table reveals that the overall costs (~ EUR 34 000 per year, ~ EUR 6.3 per p.e.) are lower than those of the ozonation with post-treatment. Additionally, this technology could also improve phosphorus removal result in the removal of certain heavy metals.

Table 11: CAPEX and OPEX of the GAC filter.

CAPEX, of which	€	a	k€/a
construction	160 000	30	5.3
post-balancing tank	150 000	30	5.0
equipment	50 000	15	3.3
ICE	15 000	10	1.5
additional costs	35 000	30	1.2
Total CAPEX	410 000		**16.3**
OPEX, of which			**k€/a**
material			3.5
electricity			0.4
staff			9.9
maintenance			2.6
Total OPEX			**16**

Additionally, it should be taken into account that the GAC filter is easier to operate compared to the ozonation. In the case of ozonation, the operator will certainly play a greater role in selecting the correct ozone dose, and in addition, the use of ozonation requires proper training. Also, a number of factors relating to safety at work are involved in ozonation. GAC, on the other hand, is a physical filtration, which is why it is certainly easier to operate. In addition, the overall cost for the GAC filter are approximately EUR 9500 per year lower than for ozonation.

Consequently, the following conclusions can be drawn as regards the implementation of the GAC filter:

- The GAC filter is universal and reduces the levels of APIs, heavy metals and other hazardous substances;
- Operation of the GAC filter is simple and therefore does not require special training;
- It is easy to combine a GAC filter with another filter material to increase the removal efficiency of phosphorus, for example;

Conclusions

This feasibility study analyzed the current status of Kohila WWTP, using data from years 2020-2021. In addition, two sampling campaigns were carried out to identify the level of APIs. It was found that the wastewater received at Kohila WWTP has a relatively low level of APIs, but for certain compounds, such as diclofenac for example, it would still be advisable to apply the treatment technology in the future.

The analysis carried out above revealed that if Kohila also wanted to establish a post-treatment technology for the removal of phosphorus in the future, the following technological solution would be appropriate, which could also be set up in stages:

Post-balancing tank-------Sand filter with GAC layer------Effluent

The post-balancing tank is certainly required to ensure a uniform load on the filters. If the intention is only reduction of suspended solids and particular phosphorus, then a sand filter with GAC layer alone would be sufficient. If further reduction of phosphorus by more than 30% should be achieved, chemical coagulation must be applied prior to the filtration. The coagulant may also be dosed straight to the balancing tank, provided that it is fully sent to the sand filter. For the adsorption of hazardous compounds, a GAC filter should be set up which removes the majority of APIs and heavy metals. As adsorption depends on a number of factors which are theoretically difficult to predict, such as the removal efficiency of different pollutants, etc., it is certainly necessary to carry out pilot tests, at least under laboratory conditions, before the final design is approved.

To sum up, it can be said that the feasibility study structure established in the framework of CWPharma project is a good tool for selecting the tertiary treatment. This will help to accurately estimate the CAPEX and OPEX of the planned technology and the links between them, i.e. which are the factors on which the corresponding costs depend. In addition, by analysing the whole process, it is easier to find possible synergies to remove other pollutants.

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