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Briefing note

Treating micropollutants at waste water treatment plants

Experiences and developments from European countries

1. Summary

European policy on micropollutants in surface water and groundwater should be based on the principles of 'Control-at-Source' and 'Polluter-Pays'. The correct use of the source control approach is also essential to protecting human health and achieving a truly circular economy. We recognise, however, that, in combination with the source control strategy, extra treatment at the level of certain urban waste water treatment plants (WWTPs) may play a role in controlling aquatic pollution deriving from micropollutants, especially from pharmaceuticals for human use. In this paper we present some considerations and recommendations to inform and assist decision makers. The end-of-pipe approach may be considered as a complementary option in specific and limited circumstances.

2. Introduction

Micropollutants are organic or mineral contaminants of anthropogenic as well as natural origin that raise considerable toxicological concerns for the aquatic environment and are often referred to as 'pollutants of emerging concern'. They can be found in waters at very low concentrations, ranging from micrograms to nanograms per litre. They can originate from industrial processes, from pharmaceuticals for human and veterinary use, personal hygiene products, industrial or household chemicals, detergents, cosmetics, textiles, pesticides, or from micro-substances in coatings or paints. Some of them have been on the EU's regulatory agenda for the past 50 years to ensure the protection of the environment and human health.

European policy towards micropollutants in surface water and groundwater should - as a priority - be based on the principles of 'Control at Source' and the 'Polluter-Pays', as enshrined in Art.191.2 of the Treaty on the Functioning of the European Union. We have consistently advocated for this in our position papers on source control for micropollutants[1], on pharmaceuticals for human use[2] and on veterinary pharmaceuticals[3].

The most sustainable solution is **to prevent micropollutants from entering the water cycle in the first place**. The correct use of the source control approach is instrumental **to achieving a truly circular economy**.

We recognise, however, that extra treatment at the level of certain WWTPs may play a role in controlling the pollution deriving from micropollutants **if it is complementary to the source control strategy.** This may especially apply to the residues of pharmaceuticals for human use that enter the aquatic environment via WWTPs.

In this paper we present some national or regional experiences related to treating pharmaceuticals at WWTPs with the intention of informing decision makers on the possibilities, limits and costs of the end-of-pipe treatment.

The presence of micropollutants in waste water effluents is only one of the factors that influence the quality of water resources[4]. Although conventional WWTPs are not designed to remove pharmaceuticals for human use, some plants have proved to efficiently remove some micropollutants (including some pharmaceuticals) through absorption or biodegradation processes (for instance ibuprofen, an analgesic anti-inflammatory drug, is almost completely removed, whereas diclofenac, another analgesic anti-inflammatory drug, is not).

In recent years, however, some countries or regions in Europe (Switzerland[5], the Netherlands, Sweden, Germany[6], Denmark and Flanders) have started to explore the extra end-of-pipe treatment at specific WWTPs with the purpose of **addressing only one specific category of micropollutants: pharmaceuticals for human use**.

While in the case of Switzerland there was a legislative act requiring the upgrade of 100 WWTPs (out of the existing 800 plants), projects in other European countries were developed on a voluntary basis.

3. The complementary approach

The following elements should be considered if public authorities wish to develop a holistic policy towards reducing micropollutants in the environment that also includes the advanced treatment of waste water **as a complementary tool to control at**

[1] http://www.eureau.org/internal-resources/eureau-final-docs/internal-position-papers/172-source-control-for-micropollutants/file.
[2] http://www.eureau.org/topics/drinking-water/drinking-water-position-papers/91-pharmaceuticals-may2014/file.
[3] http://www.eureau.org/topics/drinking-water/drinking-water-position-papers/95-contribution-to-the-european-commissions-strategic-approach-on-veterinary-pharmaceuticals-in-the-environment-october2015/file.
[4] As stated in the EEA report 'European waters'[4] (2018) the most relevant factors include hydromorphology, point-source or diffuse pollution (agricultural pressures, industrial discharges), and over-abstraction of water for irrigation.
[5] https://www.micropoll.ch/aktuell/.
[6] https://www.masterplan-wasser.nrw.de/das-kompetenzzentrum/general-information-gb/.

source measures:

1. Whether the concentrations of specific substances present in the receiving waterbody, either as individual substances or as a mixture, negatively impact the raw water quality by, for instance, exceeding the Environmental Quality Standards (EQS). In this case, measures based on the Source Control and Precautionary Principles, reducing the emissions along the whole life-cycle of a product (production, marketing, use, and disposal) should be taken as a first step.
2. The impact from micropollutants transferred via WWTPs on the ecology and/or nearby drinking water resources and whether it is an important or relevant factor, according to Art.7 (3) of the Water Framework Directive. Other factors like excess nutrients, hydromorphological factors and atmospheric deposition may be more decisive and more urgent to control.
3. Monitoring and analytical techniques to assess the impact of these substances, as these inform the view of the extent of the micropollutants' problem to solve. New techniques such as Effect Based Monitoring techniques/bioassays may be useful to make an assessment. It is essential to set out the approach to monitoring (both sampling and the analytical techniques) so that results can be interpreted and trends observed in order to inform future decisions on micropollutants.
4. Population density and dilution ratio of the WWTP effluent in the receiving water to maximise environmental benefits and minimise costs. Small WWTPs discharging in large water bodies might have negligible effects, whereas large WWTPs discharging on small waterbodies may have a negative effect. Extra treatment could have a bigger impact in the latter case, with better spreading of the costs, while it could pose more serious affordability problems in scarcely populated areas with small WWTPs.
5. The policy framework should be flexible enough to allow innovative approaches to be developed. As the issue of micropollutants is still relatively new, we expect that in the years to come new insights and technologies will be developed. This means that for the coming period, policies should be flexible, allow innovative approaches and include an evaluation of chosen strategies.

Limits

6. An additional treatment process before or after the advanced treatment might be necessary. For example, it may be necessary to add a further treatment step to reduce by-products after ozonation or a separate sludge treatment facility for activated carbon 'sludge'. Moreover, the removal of harmful substances may require a nutrient removal step before the micropollutant removal step. The choice and the costs of additional treatment stages for micropollutants are dependent upon the treatment technologies already in

place.

7. Different substances and mixtures of substances respond to the various treatment technologies in different ways. Therefore when selecting the treatment technology it must be considered that there is **no one off-the-shelf-solution for removing all micropollutants** in general. Activated carbon and ozone are promising technologies for the removal of pharmaceuticals. The effectiveness of treatment technologies depends on the variability of flows to the WWTP and the identification of the treatment endpoint. There may be a risk that the water sector spends millions of euros on additional treatments that do not deliver the expected benefits for the environment as there is insufficient removal of some substances. The costs will partly depend on the desired treatment endpoint which will define the removal requirements.

8. Once an advanced treatment solution is identified, **a full environmental impact assessment should be carried out**. Most advanced treatment techniques require the input of extra energy and/or resources: energy for ozone generation or UV treatment, the use of activated carbon, etc. Energy consumption may increase between 10-60%, depending on the chosen technologies.

9. Water treatment infrastructures have a lifetime exceeding 30-40 years, therefore an extra budget for new investments might not be readily available. It should be remembered that it takes time to commission and construct new treatment systems. Clear timelines will be needed for reductions in micropollutant concentrations from all source control actions, the expected residual concentrations arriving at WWTP and the timescale to eventually commission advanced treatment. Overall, the benefit to the water environment and the timescales to achieve these benefits, need to be balanced against the additional costs of advanced treatment, climate change impacts and affordability of waste water services.

Costs

10. A thorough evaluation of the capital and operational costs and how they will reflect on water bills is necessary. Advanced treatment will increase waste water treatment costs since the capital expenditure and the operational expenditure will increase for waste water operators. **These costs will have to be recovered through water bills and may jeopardise affordability for households**.

11. Based on the Polluters Pays Principle, **extended producer responsibility mechanisms must be introduced** so that the producers of these substances bear the costs of advanced waste water treatment.

12. From current experiences on the specific removal of residues of pharmaceuticals for human use it can be observed that cost estimates can

vary, depending on the capacity of the installation, the required efficiencies, local circumstances, applied technologies etc. The extra treatment costs can be up to 50%.

4. Experiences in European countries

EU funded projects

- NEPTUNE (FP7 research project)[7]

Part of the NEPTUNE project considered micropollutants in WWTP effluent and their removal. Several removal technologies were studied and the results allowed researchers to make a first assessment of best technologies and associated costs. The table below summarises the total costs for the two most promising technologies: ozone and activated carbon. As a comparison, for the Flemish situation the total yearly cost for traditional treatment (WWTPs and collecting network) is about €0.56/m^3 (including large investments in networks), the purely operational cost is €0.16/m^3 (data from Aquafin).

Post treatment	Dose mg/L	Electricity consumption kWh/m^3	Primary energy kWh/m^3	Costs 30.000 PE €/m^3	500.000 PE €/m^3
Ozone + sandfilter	3-10	0,1-0,2	0,3-0,6	0,15-0,2	0,05-0,07
Powder AC + filter	10-20	0,05	0,5-0,8	0,25-0,3	0,09-0,11

- TREATREC (EU Marie Curie research project)

Part of the project involved a cost-efficiency analysis for upgrading WWTPs for the removal of pharmaceuticals. The total costs used in the project for advanced treatment are given in the table below. The technology considered was a combination of ozone and sand filtration, as this technology will eliminate almost all diclofenac.

Capacity WWTP (PE)	20.000	100.000	300.000
Design capacity ozonation + sand filter (m3/h)	200	1.050	3.100
Treated volume (m3/y)	1.140.000	5.980.000	17.660.000
Realization costs (CAPEX)	1.700.000	7.300.000	19.400.000
Annual Realization costs (4% interest rate)	160.000	700.000	1.900.000
Annual Maintenance + Personel costs	50.000	170.000	370.000
Annual Variable costs (elec., pure oxygen, pumping)	45.000	240.000	690.000
Total annual cost (OPEX)	250.000	1.100.000	2.900.000
Cost/m3/y	**0,22**	**0,18**	**0,16**

[7] https://www.eu-neptune.org/.

Switzerland

Selected urban WWTP in Switzerland will be upgraded up until 2040 as part of the Swiss micropollutants action plan. The selected plants are:

- those larger than 80,000 PE to reduce the total loads,
- those in catchment areas of lakes that are larger than 24.000 PE to protect drinking water resources,
- those with an inadequate dilution larger than 8.000 PE to protect sensitive water bodies,
- those having already nitrogen removal in place, as otherwise ozonation or activated carbon costs would be unsustainable.

The associated investment is estimated at €1.2 billion, 75% of which will be financed by the consumer with an earmarked waste water fee (about €8 /person/year). The additional operational costs are estimated at €120 million. The total estimated costs (capital and operating costs) would be €15 per person per year if every Swiss person is considered and €26 per person per year if only people connected to an upgraded WWTP are considered. This represents an increase of total costs for waste water treatment of 10-15%.

Eight urban WWTP are already upgraded, four with ozone and four with activated carbon. Their legal requirement is as follows. Twelve indicator substances - mainly pharmaceuticals - are considered: "group 1" substances that can easily be removed with the additional treatment and four of which have a goal of 80% removal, and a "group 2" substances, that are not readily treatable and two of which need 50% removal. The experience of the last few years shows, that implemented technologies are continuously optimised. Thus the use of ozone and activated carbon decreases and with this their negative environmental impacts. In addition, technologies use less and less space.

The Netherlands: the STOWA study

From the STOWA study[8] carried out in The Netherlands, cost estimates vary from roughly €5/p.e./ year for vary basic treatment (addition of powder activated carbon in the aeration tank, with limited extra removal rates) to €34 /p.e./year (for small treatment plants). The total costs for the removal of micropollutants with an efficiency > 60-80% (X-ray contrast media excluded) are summarised in the table below (costs refer to cubic metre of treated water).

[8] https://www.stowa.nl/sites/default/files/assets/PUBLICATIES/Publicaties%202017/STOWA%202017-36%20%20defversie.pdf.

Capaciteit rwzi	20.000 i.e.	100.000 i.e	300.000 i.e.
Ozonisatie + zandfiltratie	€ 0,26 ± € 0,05	€ 0,22 ± € 0,04	€ 0,19 ± € 0,03
PAK + zandfiltratie	€ 0,30 ± € 0,04	€ 0,23 ± € 0,04	€ 0,21 ± € 0,03
GAK	€ 0,33 ± € 0,05	€ 0,31 ± € 0,04	€ 0,30 ± € 0,04

* De onnauwkeurigheid van ± € 0,03 - € 0,05 in deze tabel geeft de invloed weer van een DOC concentratie in het rwzi effluent van 7 of 15 mg/l ten opzichte van de aangenomen 11 mg/l

Currently there is one full-scale installation with a 1-STEPR-filter and a downstream fixed bed filter with activated carbon. In addition, in the frame of the 'Schone Maaswaterproject' (Evides), there is a full-scale pilot study with activated carbon.

Finland

The results of a Finnish study[9] show the following:

90% removal for harmful pollutants (GAC + Ozonation):

additional cost for WWTP < PE 10 000	0,56 -0,91 €/m3
additional cost for WWTP 10 000 <PE< 100 000	0,46 -0,73 €/m3
additional cost for >PE 100 000	0,4 -0,60 €/m3

It is assumed that WWTP already have an advanced treatment step to polish the nutrient removal (not included in the cost).

It was also estimated that improving the efficiency of removing harmful substances would require an investment of €700–1,400 million and increase the annual operational costs of waste water management by €100–220 million.

This corresponds to an increase of **20–30% of the current waste water charges.**

The increase of the cost of waste water treatment per person with the above mentioned estimation would amount to about €30 - 70 /person/year (assuming 0.2 m^3 WW/person/day).

[9] https://www.vvy.fi/site/assets/files/1666/jatevedenkasittelyn_teknis-taloudellinen_selvitys_21042016.pdf (page 65).

Removal of harmful substance with different methods

	Mekanismi	Fotolyysi	Biohajoa-minen	Sorptio	Hapetus	AOP	Suodatus
	Methods	UV, aurinko	Activated sludge MBR	PAC, GAC, maa-suodatus	Ozone otsoni	UV+H2O2, O3+UV jne.	RO, nano
Pharmaceutical	Ibuprofeeni						
	Hormonit						
	Sulfametoksiatsoli						
	Diklofenaakki						
	Karbamatsepiini						
Substances in Products	Bisfenoli-A						
	Triklosaani						
	artificial sweeteners						
	EHMC						
	PFOS						
Teollisuus yms. kemikaalit (Industrial Substances)	AMPA			?	?		?
	Kadmium						
	Alkyylifenolit					?	?
	BDE				?	?	?
	HBCD			?		?	?
	DEHP			?	?		?
	TBT					?	?

Red = removal < 20%
Orange = removal 20-50 %
Yellow = removal 50 -80 %
Green = removal > 90 %
Brown= no removal, goes to sludge
? no information available

...seen

...seuraavia lähteitä: Yoon ym. 2003; Ochoa-Herrera ja Sierra-...08; Pomiès ym. 2013; Liu ym. 2009; Scheurer ym. 2010; Assalin ...a Zoh, 2009; Vione ym. 2015; Rosenfeldt ja Linden, 2004; Chen 2009; Saldago ym. 2015; Shih ja Wang, 2009; Abellan ym. 2009; Vieno, 2014; Nghien ym, 2004; Koyuncy ym. 2008; Alturki ym. 2010; Thompson ym. 2011; Lange ym. 2012; Seco ym. 1999; Keen ym. 2013; Lester ym. 2014; Sharma ym. 2014; Mitchell ym. 2012; Li ym. 2007; Tsui ym. 2014; Santiago-Morales ym. 2013

Germany

By the end of 2015 there were already 17 full-scale applications with ozone and sand filtration in operation in Germany. 11 others were planned.

There is no national legislation for the introduction of a pharmaceutical residues treatment step but there are special political strategies in some political regions where this technology has been introduced/ implemented.

The following data comes from the Civity study (2018)[10] *'Costs of a fourth treatment stage in waste water treatment plants and financing based on the Polluter Pays Principle':*

The associated costs for the introduction of a pharmaceutical residues treatment step throughout Germany is estimated to be around €1.2 billion/year. This will lead to total costs of around €36 billion over 30 years.

Financing the costs of €1.2 billion /year through waste water fees would lead to an additional burden of around €15.20 per person per year. On average, the waste water fees for a four-person household in Germany would increase by €60.80. While this means an average increase of 14% in the fees, it could, in some German Länder such as Bavaria, be as high as 17%. As these figures are average values, the increase in fees could be even higher in some cases.

Sweden

Sweden defined EQS for diclofenac, 17-alfa-etinylestradiol and 17-beta-estradiol.

In the frame of the MISTRAPHARMA-project[11] one full-scale ozone installation is operational.

This Swedish report summarises process solutions and experiences from full-scale plants for advanced treatment of pharmaceutical residues and other organic micropollutants.

Denmark

Recent studies show that, on average, biological treatment removes up to 50% of pharmaceuticals. Some of the Danish water utilities are running pilot and full scale tests of extra end-of-pipe treatments to reduce the amount of pharmaceuticals being discharged. The techniques that are used are: ozonation, UV treatment, activated carbon and moving bed biofilm reactors (MBBR).

The total cost varies according to the size of the plant, and the requirements in micropollutants removal.

With ozonation technology, the total cost, including investment costs and operational

[10] https://www.bdew.de/media/documents/PI_20181022_Kosten-verursachungsgerechte-Finanzierung-4-Reinigungsstufe-_Klaeranlagen.pdf.
[11] http://www.mistrapharma.se/.

costs, is around €3.35/person/year (25kr/p.e./year). This is the cost for a full scale plant using ozonation for pharmaceutical residues removal, in operation for around five years.

In Denmark, studies are being carried out to determine which pharmaceuticals are being discharged from hospitals and from households.

According to Danish specialists, energy consumption will increase by 10-35%, when using advanced treatment. The 10% extra energy is needed when treating with ozone and activated carbon, and the 35% extra energy is needed for the MBBR process. This is a valid estimation only when adding the extra treatment at a WWTP **that already has nutrient removal in place**.