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Ministry of Infrastructure
and Water Management

THE INNOVATION PROGRAM REMOVAL OF MICROPOLLUTANTS AT WASTEWATER TREATMENT PLANTS

THE STATE OF AFFAIRS AUTUMN 2021

2021
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THE STATE OF AFFAIRS AUTUMN 2021

How do water authorities limit the emission of medicine residues and other organic micropollutants into the aquatic environment?

In this brochure you can read more about the Dutch approach to medicine residues and other micropollutants in wastewater and surface water. In particular about the state of affairs regarding the Innovation Program Removal of Micropollutants at wastewater treatment plants.

In this program we investigate the feasibility, affordability, effectiveness and sustainability of promising new removal techniques, or combinations thereof. This brochure is an update of a brochure about this program that was published in 2019.

MEDICINE RESIDUES IN THE ENVIRONMENT

A GROWING SOURCE OF CONCERN

1

In the Netherlands, but also in many other countries, there are great concerns about the presence of medicine and other micropollutants* in wastewater, surface water and drinking water. Perhaps these substances have been present for decades but for some time now we have been able to actually demonstrate their presence through better analysis techniques. However, new pollutants are also constantly cropping up. It is expected that the amount of medicine and other contaminants, as well as the concentrations found in the water, will increase further. Partly because, together we are using more and more medicine.

Many medicine residues and other micropollutants end up in the sewer: via the shower, the kitchen, the toilet (urine, faeces) and via rainwater runoff. They then arrive at wastewater treatment plants (wwtps) via the sewage system. If wwtps do not have additional treatment techniques, then only a limited part of these micropollutants is removed from the wastewater, so that many of the substances eventually end up in surface water with the treated wastewater.

Although there is plenty of research into the ecotoxicological effects of medicine residues and other organic micropollutants on aquatic life, it is becoming increasingly clear that the presence of (combinations of) these substances can pose a risk to public health and constitute an important obstacle to a healthy aquatic life and achieving established ecological water quality goals (Water Framework Directive). For the time being, there are no standards for individual medicine residues in surface water and only limited standards for other organic micropollutants.

In recent years, the necessary, interrelated initiatives have already been taken in the Netherlands to reduce the emissions of medicine residues and other micropollutants into the aquatic environment. On the one hand, managers of wwtps (the Regional Water Authorities) are taking measures to reduce emissions. On the other hand, practice-oriented innovative research is taking place. This, among other things, is happening, within the Innovation Program Removal of Micropollutants at wwtps, which we discuss in detail below.

In the Dutch approach, all parties involved work closely together to achieve results quickly: the responsible Ministry of Infrastructure and Water Management, the Dutch Regional Water Authorities, the Foundation for Applied Water Research STOWA (the knowledge centre of the water authorities), knowledge institutions and the business community. Each from his own role, task and responsibility. We are happy to tell you more about the results achieved so far.

* *This brochure is about medicine residues and other organic micropollutants. We often refer to them as 'micropollutants' in this brochure for ease of reading. Organic micropollutants (including medicine residues) contain carbon molecules, unlike inorganic micropollutants such as heavy metals.*

THE DUTCH APPROACH

LEARNING BY IMPLEMENTATION

2

As mentioned, the Dutch approach to medicine residues and other micropollutants consists of a number of closely related components. The approach is pragmatic in nature, in which practice, further development of and further research into possible measures go hand in hand. The motto is 'learning by implementation'. We consider, take action, investigate whether something works (monitoring), adjust if necessary and start working again with the results. We are exploring new treatment options for the longer term in innovative applied research, but also in more fundamental research. We use the experiences from research in practice. The insights gained in practice can form input for further research.

What does the Dutch approach consist of? The various components are listed below.

A

THE CHAIN APPROACH TO MEDICINE RESIDUES

Since 2016, Dutch central government has been working together with regional water authorities, drinking water companies and healthcare parties to find action points for reducing the amount of medicine residues that end up in the aquatic environment. In the entire medicine chain - from development, authorisation, prescription and use, to wastewater treatment - measures are being sought that are feasible and affordable.

The chain approach has been formed into an implementation program. It describes the objectives and multi-year actions at all points in the chain; from source approach at the beginning of the chain, such as medicine use in the healthcare sector and by patients, to the removal of medicine residues and other micropollutants in wwtps at the end. This approach produced, among other things, the 'Green Deal Sustainable Care'. This resulted in the government making agreements with more than 130 healthcare parties in the Netherlands, for example about prescribing medicine and returning unused medicine to pharmacies and general practitioners.

B

THE CONTRIBUTION SCHEME 'TREATMENT OF MEDICINE RESIDUES' AND THE ACCELERATION PROGRAM

An important part of the aforementioned chain approach is the 'Treatment of Medicine Residues' contribution scheme of the Ministry of Infrastructure and Water Management (I &W), plus the related Acceleration Program.
The ministry provided 60 million euros to stimulate the implementation of medicine residues removal techniques on a practical scale. Water authorities that use such techniques can make use of this contribution. The condition is that the installations remain in operation for at least ten years, that they have a minimum removal efficiency of 70 percent (of seven of the eleven selected guide substances; see also Guide Substances box) and that the effectiveness of the applied technology is monitored. The conditions for eligibility for financial support from the government have been further elaborated in the Acceleration Programme. Proven techniques are being realised at a number of so-called hotspot locations.

The great strength of the Contribution Scheme and the Acceleration Program is not only the fact that in practice more and more treatment plants are removing medicine residues. Water managers also collect very valuable information about the operation and effectiveness of the applied techniques through monitoring over a longer period of time. Not just about the removal efficiencies of the so-called guide substances, but also, for example, about the biological effects. The same water managers also gain a lot of insight into the costs for management and maintenance, and into the robustness of the techniques that have been implemented because the installations have to run for at least ten years to be eligible for a financial contribution.

Thanks to the Contribution Scheme and the Acceleration Programme, nine water authorities will put the proven techniques ozone, activated carbon (powdered carbon dosing and granular activated carbon filtration, for explanation see page 11 and 12) or combinations of these into operation via working installations before the end of 2023. This is happening at twelve wwtps with more being added before the end of 2027. The water authorities themselves also contribute financially to these working installations.
In short: thanks to the Contribution Scheme and the Acceleration Programme, all parties involved are broadening and deepening their practical knowledge about the removal of medicine residues and other micropollutants.

C

THE HOTSPOT ANALYSIS

The Dutch water authorities, responsible for the treatment of municipal wastewater, manage a total of more than 300 wwtps. Hotspot analysis was carried out as it is impractical and also not very cost-effective to start taking measures at random installations. This raises

the question: at which of these installations does taking measures to remove medicine residues have the most effect? The hotspot analysis can be used to determine the severity of emissions and to identify locations where the effectiveness of any measures to reduce those emissions is greatest. For example, because of the ecological water quality, or with a view to intake points for the production of drinking water. More information about the hotspot analysis can be found in the report National hotspot analysis of medicines (STOWA 2017-42).

D

THE INNOVATION PROGRAM REMOVAL OF MICROPOLLUTANTS AT WASTEWATER TREATMENT PLANTS (DUTCH: IPMV)

As indicated earlier, the Dutch government provides financial support to water authorities to install additional (post-treatment) installations at their wwtps for the removal of medicine residues and other micropollutants. At the same time, the government is providing money for further research into new promising removal techniques. These studies have been brought together in The Innovation Program Removal of Micropollutants at wastewater treatment plants, IPMV for short. This program is discussed in detail in the next chapter.

E

THE RESEARCH PROGRAM 'CONTAMINANTS OF EMERGING CONCERN IN THE WATER CYCLE'

The Netherlands Organisation for Scientific Research NWO, the knowledge institute KWR, TKI Water Technology and STOWA - the Dutch acronym for 'Foundation for Applied Water Research' - joined forces in 2017 to work on what they describe as 'a groundbreaking approach' to medicine residues and other micropollutants. According to the parties involved, this is necessary in order to be effective in the long term in tackling medicine residues and other micropollutants.

The program includes five major studies, subdivided into three themes. The first concerns correct monitoring of the effects of substances, and above all: combinations of substances on aquatic life. If we can monitor the effects correctly, we can also provide better insight into the effects of the measures taken. The second theme concerns new treatment techniques. The program is looking for promising alternatives to existing techniques, techniques with a low energy and chemical consumption at acceptable costs. The third and final theme concerns the development of an effective strategy of measures to achieve the goals in this area. A number of instruments are being developed for this, including decision support models. The results are expected in 2022.

More information www.stowa.nl/cec

IN DEPTH

INNOVATION PROGRAM REMOVAL OF MICROPOLLUTANTS AT WASTEWATER TREATMENT PLANTS (IPMV)

3

Partly at the request of the water authorities, national government has provided money for further practical research into new promising removal techniques. These studies have been brought together in the IPMV-program, the Dutch acronym for 'Innovation Program Removal of Micropollutants at wastewater treatment plants'. The Foundation for Applied Water Research STOWA coordinates the implementation of this programme. The foundation is also a co-financier.

The aim of this program is to quickly pave the way for promising new techniques, improvements of existing techniques or innovative combinations of promising and existing techniques. In this way, within five to seven years, water authorities will have more removal techniques at their disposal from which they can make the best choice for their own wwtps.

The program mainly revolves around providing answers that still exist about these (combinations of) techniques, in particular with regard to:

* the removal efficiency of selected guide substances (requirement >70 percent for seven of the eleven selected guide substances);
* the extent to which ecotoxicological risks due to discharge of wastewater into surface water are limited compared to the reference techniques;
* the costs compared to the reference techniques;
* the sustainability (CO_2 footprint) in relation to the reference techniques.

TABLE 1 *Quantitative criteria Innovation program Micropollutants from wwtp wastewater, reference techniques*

	Unit	PACAS	Ozon + sand filter	GAC***
CO_2 footprint	g CO_2/m^3 *	116	119	325
Costs	€/m^3 *	0,05	0,17	0,26
Removal efficiency guide substances Ministry of I&W	% **	70-75%	80-85%	80-85%

* *Per m^3 of treated wastewater; calculated using standard method*

** *Removal efficiency for a minimum of seven of the eleven selected guide substances benzotriazole, carbamazepine, diclofenac, irbesartan, gabapentine, metropolol, hydrochloorthiazide, mixture of 4- and 5-methylbenzotriazole, sotalol, trimethoprim and venlaflaxine. in any 24-hour or 48-hour flow rates - or time-proportional sample, taking into account the residence time of the water in the wwtp. These 11 guide substances have been chosen to monitor the effectiveness of a treatment technique for additional removal of micropollutants from wwtp wastewater and are not related to any environmental hazard.*

*** *Excluding removal of nutrients.*

The following three (combinations) of techniques have been chosen as reference techniques that are already being applied on a practical scale:

* PACAS, or: Powder Activated Carbon in Active Sludge. In this case, powdered activated carbon is dosed into the existing activated sludge tanks of a wwtp;
* Ozonation in combination with sand filtration. Micropollutants are first broken down by dosing ozone (O_3), after which the transformation products and are further removed with a sand filter;
* GAC, or: Granular Activated Carbon Filtration. Micropollutants are bound to granular activated carbon in a filter, while bacteria that can remove nutrients can also grow on the carbon granules.

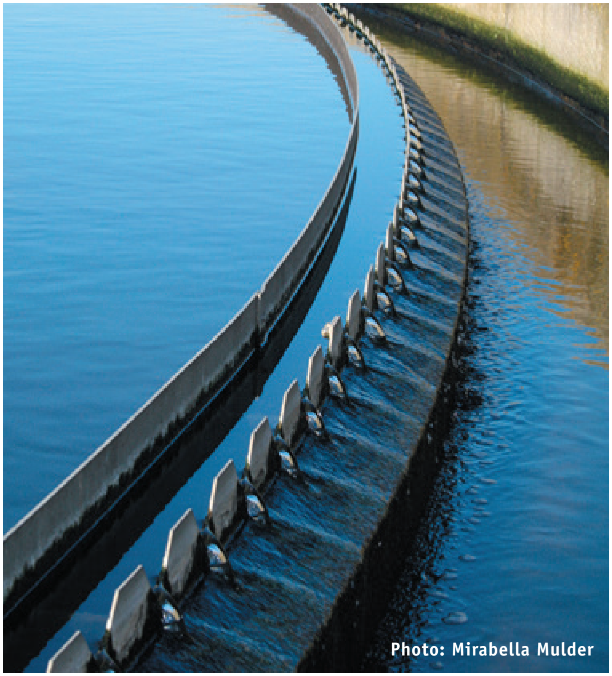


Photo: Mirabella Mulder

We also want to gain more clarity as to whether the techniques can be properly integrated into Dutch wwtps and what effects may occur in the operational management and treatment process of the wwtp.

The program has a budget of approximately €11.5 million. This is raised by the Ministry of Infrastructure and Water Management (5 million), STOWA (2.5 million) and the joint Dutch water authorities (4 million). The program started in 2019 and will run until the end of 2023. The IPMV focuses on five research themes. In two public rounds in 2018 and 2020, interested water authorities and other parties could submit proposals. The themes concern:

1

OXIDATIVE TECHNIQUES

There is a range of so-called oxidative post-treatment techniques with which micropollutants in wwtp wastewater are broken down and converted into other, less harmful substances. Of these, ozonation (in this case the dosing of O_3) in combination with sand filtration (whereby the transformation products are further removed from the wastewater) is most commonly used, especially abroad. The first practical installation at wwtp Houten will be put into use in 2021. In addition to ozone, other technologies can also be used for the conversion, for example UV light or hydrogen peroxide, whether or not in combination with ozone.

The oxidation techniques are effective, but when applied, harmful transformation substances can be formed, which from an ecotoxicological point of view, can be more harmful than the parent substance. An example of this is the conversion of bromide to persistent bromate during ozone dosing. The mechanisms under which this takes place and to what extent this determines the design of an oxidative technique are not yet sufficiently clear. At the moment, (autumn 2021) research into these tranfsormation products is underway.

Important questions within this theme are whether there are combinations of cost-effective oxidative techniques in which the risk of the formation of harmful transformation products is much smaller than with current techniques, and how the formation of harmful transformation products can be limited.

2

POWDERED ACTIVATED CARBON (PAC)

Dosing activated carbon in powder form is a proven, cost-effective method of removing micropollutants. The removal takes place via adsorption (binding) of impurities to the activated carbon until it is saturated. Then the carbon must be replaced. The saturated activated carbon is incinerated together with wwtp sludge. In Germany and Switzerland, powdered activated carbon is already being used full-scale at more than 20 wwtps to extensively remove micropollutants from wastewater. This can be done in special tanks after the existing treatment process (so-called post treatment through PAC adsorption), but also by dosing powdered carbon directly into the activated sludge tanks (PACAS).

Important questions within this theme are whether the dosing of powdered activated carbon in combination with, for example, screen filtration, or the addition of ferro compounds, leads to a better score on sustainability. In other words: a lower CO_2 footprint due to less consumption of (fossil) activated carbon. The influence of powdered carbon on the amount of surplus sludge and its composition is also being examined as well as to what extent this has consequences for sludge digestion and further sludge processing. Finally, research is being conducted into the extent to which powdered carbon particles end up in wwtp effluent and the effects of this.

3

GRANULAR ACTIVATED CARBON (GAC)

Granular activated carbon, in contrast to powdered activated carbon, consists of granules. These granules ensure adsorption of micropollutants in a carbon filter that is placed after an existing treatment process, just like with powdered activated carbon. The main difference is that the granules are active in a filter bed. No additional step is required to separate the carbon from the treated water, as is the case with powdered activated carbon. This is done via settling or (screen) filtration. Another difference is that simultaneously bacteria grow on the granular carbon which remove macropollutants such as phosphate and nitrogen. For the first time in the Netherlands, a full-scale granular activated carbon filter has been built at wwtp Horstermeer, a filter that removes phosphate, nitrogen and micro-pollutants in one step. Hence the name ‘1-STEP filter’.

In practice it appears that the 1-STEP filter is effective for micro- and macropollutants. But the so-called working life for removal of micropollutants is short; after just three months, the removal efficiency for micropollutants decreases sharply, although nutrients are still largely removed. This makes the exploitation of the technology relatively expensive, because the carbon has to be regenerated afterwards. But the advantages are clear: no chance of formation of harmful transformation substances as with oxidative techniques. In addition, GAC filters also catch other macropollutants. A variant of the 1-STEP filter is the O3-STEP filter in which the 1-STEP filter is combined with ozone dosing. The working life of the activated carbon can then be much longer.

The challenge within this theme is mainly to improve or extend the functioning of the filters for micropollutants. This reduces costs and increases the effectiveness of this technique.

4

FILTRATION

Nanofiltration is a process that has been used for some time in the production of drinking water. Water is forced under pressure through a membrane with very small filter pores (between 1 and 10 nm). Nanofiltration of effluent seems promising for far-reaching removal of micropollutants, higher than ninety percent.

A challenge is the way in which the separated fraction containing the micropollutants is treated. Moreover, drinking water has a completely different composition than treated wastewater. This requires further lab research and pilot research. In view of the high removal efficiency of filtration techniques, it is interesting to examine how nanofiltration can be applied cost-effectively and can be integrated into existing wastewater treatment plants. The treated water is of very good quality and is attractive for use in other applications.

5

ALTERNATIVE ADSORBENTS

As indicated above, binding or adsorption of micropollutants to activated carbon is already being applied on a practical scale, especially abroad. The returns are high, the costs are relatively low. However, the activated carbon used is usually of fossil origin (coal). The challenge is to produce the powdered carbon more sustainably (with a lower CO_2 footprint), or to replace it with alternative adsorbents, such as Zeolite or cyclodextrins.

RESULTS AND ONGOING STUDIES

In the first round of the innovation program, which started in 2018, sixteen projects were initiated within the five themes. In most cases, this involved carrying out feasibility studies in which the submitting parties were allowed to demonstrate that the (combination of) techniques they proposed provide added value (in terms of effectiveness, costs, sustainability) compared to the aforementioned reference techniques.

If the outcome was successful, the applicants were given the opportunity to further investigate the feasibility in a pilot. At the moment (autumn 2021), nine projects have reached or completed the pilot phase. These are: 1.

PAC-O_3 at wwtp Leiden-Noord; 2. Powder-activated carbon plus screen filtration at wwtp Vinkel; 3. Powdered carbon dosing in Nereda at wwtp Simpelveld; 4. O3 step filter at wwtp Horstermeer; 5. BODAC at wwtp Emmen; 6. Water factory Wilp at Terwolde; 7. Ozone in combination with ultrasound at wwtp Winterswijk; 8. Nanofiltration at wwtp Asten. 9. Upflow GAC filtration at wwtp Hapert.

The second round of the innovation program started in mid-2020, for which parties could once again submit project proposals. A total of 28 project proposals were submitted for this phase. The proposals were re-evaluated for costs, efficiency and applicability in relation to the reference techniques. However, more emphasis was placed on the sustainability of the techniques. A Wastewater treatment plant with post-treatment produces on average 40 percent more CO_2 emissions than without it. While at the same time Dutch water authorities have the ambition of being energy neutral by 2030. Post-treatment techniques can therefore make this task considerably more difficult.

Based on the assessments, a number of proposals have been given the green light for carrying out a feasibility study. These started at the beginning of 2021.

More about the feasibility studies carried out and the pilots mentioned above can be read below.


Wastewater treatment plant Groote Lucht

WHICH GUIDE SUBSTANCES ARE LOOKED AT AND WHY?

In the Netherlands, the effectiveness of the (post) treatment techniques to be studied is determined, not only by biological effect measurements, but also on the basis of the removal efficiency of a number of substances pre-selected by the government, the so-called guide substances. The effectiveness of the various techniques can best be compared by monitoring the same guide substances in all pilot studies, demonstration installations and full-scale installations.

It concerns the following eleven substances: benzotriazole, carbamazepine, diclofenac, irbesartan, gabapentin, metoprolol, hydrochlorothiazide, mixture of 4- and 5-methylbenzotriazole, sotalol, trimethoprim and venlafaxine.

The choice of these substances is intended to be able to monitor the performance characteristics of extensive treatment techniques as clearly as possible; the guide substances do not provide an indication of the extent to which the substances pollute the environment.

Commissioned by STOWA and the Ministry of Infrastructure and Water Management, the Dutch water authorities' laboratories have developed an unambiguous sampling and analysis method for micropollutants in wastewater. In this way, the analysis results of all laboratories can be optimally compared to each other. You can read the outcome of this in the STOWA report 2021-15 'Determining the removal efficiency of medicine residues from wwtp wastewater'.

RESULTS AND ONGOING STUDIES POWDERED ACTIVATED CARBON (PAC)

1

FEASIBILITY STUDY AND PILOT STUDY PAC-O_3 FOR REMOVAL OF MICROPOLLUTANTS AT WWTPS (STOWA 2021-23)

PAC-O_3 is a promising concept for extensive removal of micropollutants. It consists of a combination of adsorption (via powdered carbon) and oxidation (ozone/O_3), two different reaction mechanisms with which a large diversity of micropollutants can be removed. In addition, higher removal efficiencies are achieved in comparison to the separate reference techniques PACAS and ozonation.

The feasibility study shows that compared to the reference techniques, PAC-O_3 scores better on the range of micropollutants to be removed and can achieve better results. The risk of bromate formation is smaller compared to ozonation due to the lower ozone dose; sludge production is lower than with PACAS due to the lower dosage of activated carbon. The CO_2 footprint of PAC-O_3 is equal to the reference techniques.

On the scale of a 100,000 i.e. wwtp, the costs are slightly higher than those of PACAS at € 0.10 per treated cubic meter of wastewater and lower than ozonation in combination with sand filtration for 70 percent removal efficiency on guide substances. A higher efficiency than the reference techniques is also achievable at acceptable costs (similar to ozonation in combination with sand filtration).

Pilot

The next step in the development of the PAC-O_3 concept is the execution of pilot tests. This research takes place at the wwtp Leiden-North. It focuses, among other things, on accurately quantifying the distinction between the PAC-O_3 concept and the reference techniques PACAS and ozonation. The removal of a wide selection of micropollutants will be specifically investigated. In addition, aspects such as bromate formation and sludge production will be studied. The study started in 2021, results are expected in 2022.

2

FEASIBILITY STUDY AND PILOT PAC PLUS CLOTH FILTRATION FOR REMOVAL OF MICROPOLLUTANTS AT WWTPS (2020-21)

In this feasibility study, the combination of powdered-activated carbon and cloth filtration was compared with the reference technologies PACAS, GAC filtration and ozonation in combination with sand filtration. In Germany, the technology in which powdered carbon dosing is combined with screen filtration is already being applied on a practical scale at some wwtps.

Due to the lower consumption of powdered activated carbon, PAC plus cloth filtration scores better in comparison to the other proven techniques on CO_2 footprint. Due to the extensive removal of phosphate, the technology also contributes to achieving very low concentrations of phosphate in effluent.

This has a positive effect on achieving the Water Framework Directive targets. Due to the lower consumption of powdered activated carbon, sludge production is also lower and powdered activated carbon can be kept separate from the excess sludge from the activated sludge process. This offers the option of separate disposal and processing.

Powdered activated carbon plus screen filtration technology scores well on the removal efficiency of micropollutants, a required minimum removal efficiency of seventy percent for seven of the eleven selected guide substances can easily be achieved. In addition, the technology offers scope for achieving higher removal percentages, because it can also be operated at higher dosages of powdered activated carbon without this having an impact on civil, mechanical and electrical installations.

Pilot

Based on the results of the feasibility study, it was decided to conduct a pilot study at the wwtp Vinkel. This will provide insight into how the technology works in a Dutch wwtp. In addition, the focus of the pilot is on the further development of the technology. Aspects that will be investigated in the pilot tests are reducing the space requirement and thus reducing costs, gaining insight into the relationship between powdered activated carbon dosing and removal efficiencies of the guide substances, as well as the removal of various phosphorus fractions. The pilot started in 2021, results are expected in early 2022.

3

FEASIBILITY STUDY OF SUSTAINABLE ALTERNATIVES TO POWDERED ACTIVATED CARBON FOR PACAS (STOWA 2020-19) + LABORATORY RESEARCH SUSTAINABLE ALTERNATIVES TO POWDERED ACTIVATED CARBON (STOWA 2021-24)

A feasibility study has been carried out into sustainable alternatives to powdered activated carbon (PAC) from coal and lignite (brown coal). The use of regular powdered activated carbon has a negative effect on the sustainability of PACAS, because the carbon is of fossil origin and cannot be regenerated.

Sustainable PACs were listed on the basis of interviews with market parties and experts and a literature study. Based on this, the researchers have drawn up a list of the nine most promising sustainable PACs. These sustainable alternatives have been further researched in a laboratory. The removal efficiency of micropollutants of various sustainable PACs was compared with the powdered carbon used in previous research into PACAS. The sustainability and costs of sustainable PACs were also made clear and the researchers mapped out the available organic residual flows for the production of sustainable PACs.

Based on the study, the researchers concluded that the alternatives studied are equivalent, and in some cases even better than powdered activated carbon from coal and lignite. The sustainable PACs studied are already commercially available. It is expected that the cost of using them will be equal to the use of fossil PACs. This makes it possible to make the removal of organic micros with traditional powdered carbon from coal and lignite in activated sludge tanks (PACAS) sustainable in the short term.

4

FEASIBILITY STUDY AND PILOT POWDERED ACTIVATED CARBON DOSING IN NEREDA FOR THE REMOVAL OF MICROPOLLUTANTS AT THE WWTP SIMPELVELD (2020-20)

Nereda® is a new treatment technique that is now being used at ten wwtps in the Netherlands and is also on the rise abroad. The technology is characterised by the fact that the activated sludge does not form flakes but rapidly settling granules, so that the space required by a treatment plant remains limited; no secondary settling tanks are required. In addition, the technology is characterised by very good treatment efficiencies and relatively low energy consumption. The question is whether it is possible to dose activated powdered carbon in Nereda installations.

A pilot study showed that powdered activated carbon dosing is expected to be applicable without restriction. The application probably scores better on CO_2 footprint and costs criteria, and equal on the removal efficiency criterion compared to powdered carbon dosing in regular activated sludge systems (PACAS). The combination of powdered carbon and Nereda® has not yet been applied on a practical scale.

Pilot

Based on the results of the feasibility study, it was decided to conduct pilot research at the wwtp Simpelveld. The pilot is taking place on a demo scale. The results from this pilot can be immediately applied to other Dutch wwtps. The study started in 2021, results are expected at the end of 2022.

5

RESEARCH INTO PAC IN SLUDGE. EFFECT ON CURRENT AND FUTURE SLUDGE FINAL TREATMENT (STOWA 2020-34)

In the PACAS process, powdered activated carbon is dosed to activated sludge to remove micropollutants. This changes the quality and quantity of the sludge to be disposed of. This IPMV study investigated exactly what these effects are.

The research shows that powdered carbon dosing leads to a limited increase in the amount of activated sludge. Autonomous developments such as a higher wastewater supply and/or more or better fermentation often have a greater impact on the processing capacity than the presence of powdered carbon in sludge. At national level, the influence of the presence of powdered carbon on processing capacity therefore appears to be limited.

The presence of powdered activated carbon in sludge can affect the disposal options for residual products, the treatment and discharge of the wastewater produced from the sludge final processing and compliance with the emission requirements for the produced flue gases. This is caused by the fact that, in addition to medicine residues, substances of great concern such as PFAS and arsenic may also adhere to powdered carbon. More research is needed on this point.

The most important advice from this report is to explicitly take into account the impact on final sludge treatment when deciding whether or not to remove micropollutants via powdered carbon dosing at a wwtp.

6

STUDY POWDERED ACTIVATED CARBON MEASUREMENT IN WWTP EFFLUENT, INCLUDING DRAWING UP A MEASUREMENT METHOD FOR POWDERED ACTIVATED CARBON

A disadvantage of powdered activated carbon dosing is the leaching of powdered carbon via the treated wastewater, the wwtp effluent. This can occur with PACAS as well as with downstream powdered carbon variants. The amounts are assumed to be small, but this is not certain. Foreign results provide insufficient insight into this, especially because quantification is difficult and expensive, the applied technologies in Germany and Switzerland differ (PACAS is rarely used) and the powdered carbon dosage is generally lower.

In order to gain insight into this for the Dutch situation, methods are compared in this project to quantify powdered carbon in effluent. For this project, experiences and knowledge from abroad is collected and lab tests carried out. Based on this, a measurement protocol will be drawn up for the technologies that are being researched and used in the Innovation and Acceleration Program. This is used to gather knowledge about the amount of powdered carbon that can be leached, depending on the chosen technology and dosage. The project started in early 2021. Delivery of the measurement protocol is planned for early 2022.

RESULTS AND ONGOING STUDIES GRANULAR ACTIVATED CARBON (GAC)

1

FEASIBILITY STUDY AND PILOT BODAC: BIOLOGICAL ACTIVATED CARBON FILTRATION WITH OXYGEN DOSING (STOWA 2020-46)

A feasibility study has been conducted into the potential of “Biological Oxygen Dosed Activated Carbon” (BODAC, also: BAKF) for the removal of medicine residues from wastewater. The wwtp Emmen in the Netherlands has used a BODAC installation since 2010, which involves the filtration of pre-treated wwtp effluent with granular activated carbon under oxygen-rich conditions. This installation, operated by NieuWater, a joint venture of water authority Vechtstromen and Waterbedrijf Drenthe (WMD), is used for the production of ultra-pure water (UPW) from wwtp effluent. This water is used to produce steam needed for oil extraction in a nearby oil field.

Although the BODAC installation in Emmen was originally designed and built to prevent biofouling on the reverse osmosis membranes used, the technique also appears to extensively remove medicine residues and other organic micropollutants from effluent even while the granular activated carbon has not been replaced since the start-up in 2010. Although the working is not fully understood, it is likely that medicine removal occurs through a combination of adsorption, desorption and biotransformation.

Based on the results of the feasibility study, BODAC appears to be an attractive technique for the removal of micros from wastewater because high removal percentages for medicine and other organic micropollutants can be achieved. The technique has a relatively low energy consumption and low CO_2 footprint because of the absence of activated carbon regeneration. This also has a favourable effect on costs. BODAC is relatively simple and widely applicable in current wastewater treatment practice.

The main challenge is that pre-treatment is likely to be required for optimal operation. In Emmen this is now done via ultrafiltration. In order to be competitive as a post-treatment technology, a simpler and cheaper method of pre-filtration is desirable. This simple pre-treatment is currently being investigated in pilot research, as a follow-up to this feasibility study. This pilot study is taking place at the wwtp Emmen, parallel to the current BODAC installations. It also examines the extent to which there is adsorption or biological conversion, or both. The study will start at the end of 2021, results are expected at the beginning of 2023.

2

FEASIBILITY STUDY ARVIA NYEX™ TECHNOLOGY: A TREATMENT TECHNIQUE FOR THE REMOVAL OF MICROPOLLUTANTS AT WASTEWATER TREATMENT PLANTS (STOWA 2020-17)

The so-called Arvia Nyex™ technology consists of a filter bed with its own adsorption medium (Nyex™) that binds organic micro-pollutants on its surface. By applying electrical current to the filter medium, the adsorbed compounds are oxidized. This enables continuous regeneration of the adsorption medium and thus continuous process operation. In theory, this leads to a high process efficiency and complete decomposition of the organic pollutants.

During the research into the feasibility of this technology, it appeared that the technology is still under development. According to the researchers, the technology has potential. At the moment it is not possible to conclude that the technique outperforms the IPMV reference techniques, especially due to the high energy consumption. That is why this feasibility study has not yet been followed up in a pilot

3

FEASIBILITY STUDY AND PILOT O3-STEP® FILTER (2020-18)

A feasibility study has been carried out into the so-called O3-STEP® filter, a combination of ozonation and granular activated carbon filtration for the removal of medicine residues, other micropollutants and nutrients. This combination must in particular provide a solution for the relatively short operating time of the granular activated carbon filter for micropollutants (see also theme 3. Granular activated carbon).

The study shows that the combination is a promising concept for the extensive removal of nutrients, suspended solids and micropollutants in one compact treatment step at larger wwtps. The O3-STEP® filter scores better on all criteria than the reference technique GAC. The filter removes on average more than 95 percent of the selected guide substances. The costs are around € 0.12-0.14 per m^3 of treated wastewater, making it competitive with ozonation in combination with sand filtration.

Pilot

At the end of 2020, a pilot study was started at the wwtp Horstermeer This focuses on the full integration of the ozonation step and the carbon filter in continuous operation in order to demonstrate the combination of nutrient and micropollutant removal over a longer period of time. The results are expected in 2022.

4

FEASIBILITY STUDY UPFLOW GAC FILTRATION

Upflow GAC filtration is a continuous filtration process using granular activated carbon in a filter that is fed from below instead of from above, keeping the entire filter bed in motion (so-called fluidized bed filtration). Due to the relatively small grain size that is used, it is expected that less granular activated carbon is needed to bind the micropollutants. In addition, the granular grains can be regenerated, which is not the case with powdered activated carbon. This benefits sustainability. Compared to PACAS and Ozone in combination with sand filtration, the CO_2 footprint is approximately halved. The costs are comparable to ozonation in combination with sand filtration.

Based on the results of the feasibility study, it was decided to conduct a pilot to further substantiate the results at the wwtp Hapert. The pilot started in 2021 and the results are expected at the end of 2022.

5

FEASIBILITY STUDY BIOLOGICAL CONTINUOUS FILTRATION GAK

This project investigates the feasibility of biologically activated continuous filtration over granular activated carbon (BC-GAK), a new combination of techniques for the (post-) removal of micropollutants from effluent.

The researched technology concerns granular activated carbon filtration (GAC) in a continuous filter, in which the biological activity on the activated carbon medium is improved by introducing oxygen or air into the feed water to be treated. The activated carbon granules are therefore both a material on which bacteria grow that break down micropollutants and a binder of micropollutants. In short: partial break down, partial binding. It is expected that in this way more adsorption area will become available for the binding of micropollutants to the activated carbon. As a result, the activated carbon filter continues to function longer and better. The results of this study are expected at the end of 2021.

HOW DO YOU REMOVE MEDICINE RESIDUES FROM WASTEWATER?

There are roughly three methods for removing medicine residues from wastewater, adsorption (binding), oxidation (degradation) and filtration (separation). These are sometimes used separately, but also often in combination with each other.

During **adsorption**, the harmful substance binds to another substance, such as powdered activated carbon, granular activated carbon (granules) or other adsorbents such as zeolites and cyclodextrins. To keep this binding reaction going, there must be sufficient adsorbent in the system with free binding sites. This is done by continuously dosing the adsorbent, as is done with the PACAS method. Powdered activated carbon is continuously dosed into the activated sludge tanks. The filter material of granular filters has to be replaced regularly, or the activated carbon has to be 'regenerated', whereby binding sites are again freed on the carbon to bind medicine residues.

Powdered carbon cannot be regenerated. When the powdered carbon is 'full', it is separated from the wastewater and processed with the treatment sludge. In most cases, that means it is incinerated.

Substances bound to granular carbon are incinerated during the regeneration of the granular carbon. This also applies to the use of other adsorbents.

During **oxidation**, a chemical reaction takes place in which the harmful substance is actually broken down. This is done by adding oxygen, ozone or UV light. The oxidation techniques are effective, but when applied, harmful transformation products can be formed, which from an ecotoxicological point of view, can be more harmful than the parent substance. An example of this is the conversion of bromide to the persistent bromate during ozone dosing. When applying, it is important to limit the formation of harmful transformation products to a minimum. In some cases a sand filter is added for post-treatment.

The degraded substances are discharged with the treated wastewater. This raises the question to which extent the degraded substances are (still) harmful, or at least less harmful than the parent substance?

Filtration is a physical separation process in which harmful substances are separated by filtration through membranes. To remove medicine residues and other micropollutants, membranes with very fine pores (1 to 10 nanometres) are used, through which water is forced under high pressure. This is called nanofiltration.

High removal efficiencies can be achieved with nanofiltration. The challenge mainly lies in the way in which the separated fraction (the concentrate), which contains the micropollutants, must be treated further. This requires techniques that can then break down the concentrate into separate substances that can be reused or processed as waste.

RESULTS AND ONGOING STUDIES OXIDATIVE TECHNIQUES

1

PILOT STUDY COMPARING OXIDATIVE TECHNIQUES EFFLUENT WWTP AARLE-RIXTEL (STOWA 2020-41)

Pilot research was carried out at the wwtp Aarle-Rixtel into the application of two oxidative techniques: ozone with biological post-treatment (O_3+Bio) and UV with hydrogen peroxide (UV+ H_2O_2). Ozone is a technique that is already being applied at wwtps abroad. The UV+ H_2O_2 technique is a promising technique that has not yet been applied to wwtps, but is used for the removal of insecticides from wastewater from greenhouse horticulture and for drinking water production.

For the treatment of wastewater of wwtp Aarle-Rixtel, the application of ozone scores better than UV+ $H_2O_2$2 in terms of removal efficiency and associated energy consumption. For the application of UV plus H_2O_2, it is therefore necessary to wait for LED lamps with a (much) lower energy consumption before this technology is applicable for treatment of wwtp effluent. Where ozonation, is concerned, bromate formation on the specific wwtp effluent of Aarle-Rixtel can be a problem due to its high bromide content.

2

DESK STUDY INTO THE EFFECTS OF OXIDATION PRODUCTS FROM WWTP EFFLUENT

This project involves a desk study on the formation, effects and control of oxidation products when applying oxidative techniques to wwtp effluent for the removal of micropollutants. Based on this, a guideline will be drawn up for decision-making about whether or not to apply these techniques, and under which conditions. The results are expected at the end of 2021.

3

FEASIBILITY STUDY AND PILOT ULTRASOUND IN COMBINATION WITH OZONE TECHNOLOGY (STOWA 2020-24)

This study investigated the possibilities of ultrasound in combination with ozone technology for the removal of medicine residues and other micropollutants from wastewater. This technology combines the dosing of ozone with the introduction of ultrasound. This is expected to bring about a better and faster ozone transfer in water. Ultrasonic sound is in principle imperceptible to the human ear. It starts from about 20 kHz and runs up to 800 MHz. Compared to the reference technique ozone in combination with sand filtration, the combined application scored equally (costs) or better (removal efficiency and CO_2 footprint) on all criteria.

Pilot

Based on these results, additional pilot research was started in mid-2021 at the wwtp Winterswijk. At the end of this pilot study, the performance will be compared to the results of the feasibility study and any scaling up to demo scale and full scale application will take place. These results are expected at the end of 2022.

4

FEASIBILITY STUDY BO_3 TECHNOLOGY

The BO_3 technology is a combination of biodegradation and ozone treatment. The innovative element is the specific biological treatment of the treated wastewater prior to the ozone treatment. This breaks down as much as possible dissolved organic material (so-called DOC).

All this results in making conventional ozonation more sustainable because much less ozone needs to be dosed (in this case a reduction in CO_2 footprint). This also limits the potentially harmful bromate formation. The technology is characterised by the wide range of micropollutants that are broken down. The results of this study are expected at the end of 2021.

5

FEASIBILITY STUDY MICROFORCE

Microforce ++ is a combination of biological degradation (via the formation of biofilm on carrier materials) and ozone technology. As a result, the ozone dosage can remain relatively low resulting in lower energy consumption. The water is first treated via oxidisation with ozone, specifically attacking the micropollutants. As a result, non-biodegradable molecules are converted into smaller, biodegradable components that are then broken down in a sustainable, biological way using biofilm-on-carrier technology (biofilm on sand grains). The results of this study are expected at the end of 2021.

RESULTS AND ONGOING STUDIES FILTRATION TECHNIQUES

1

FEASIBILITY STUDY AND PILOT HOLLOW FIBRE NANOFILTRATION FOR REMOVAL OF MICROPOLLUTANTS AT WWTPS (STOWA 2020-22)

In this study, the technical feasibility of hollow fibre nanofiltration (NF) was researched for post-treatment of wastewater in the Netherlands. This showed that the CO_2 footprint of the technology is higher than the reference techniques PACAS and ozone plus sand filtration, but not higher than the reference granular activated carbon filtration.

The technology is also more expensive than the reference techniques. However, when using NF the post-treated wastewater (the permeate) is of such good quality that it can possibly be reused in industry or glasshouse horticulture. According to the researchers, this makes the application interesting in the context of the desire to turn wastewater treatment plants into water factories.

Pilot

The possibilities of NF are being further investigated in a pilot at wwtp Asten by the water authority Aa en Maas. Attention is also paid to the effects of introducing the NF concentrate stream back into the biological treatment process. The results of this pilot are expected at the end of 2022.

2

FEASIBILITY STUDY AND PILOT HEALTHY WATER AT WWTP WERVERSHOOF (2020-25)

In this project, STOWA and the water authority Hollands Noorderkwartier are working closely with drinking water company PWN and PWN Technology. There is a reason for this. Wwtp Wervershoof discharges the treated wastewater indirectly into the IJsselmeer lake. A few kilometres from the discharge point, the drinking water company in turn takes in water for the production of drinking water and industrial water.

In this feasibility study, research is carried out into the possibilities of reusing effluent via extensive post-treatment. This is done under the title 'Ge(o)zond'. Lab-scale research shows that the ozone dosage has a positive influence on the performance of the ceramic membranes used for post-treatment. This means that with relatively low ozone consumption, the goal of reusing wwtp effluent comes into view at costs lower than 50 euro cents per m^3 of treated wastewater.

Pilot

Based on the results of the feasibility study, it was decided to conduct a pilot at the wwtp Wervershoof to further substantiate the results. This pilot started in 2020 and the results are expected in early 2022. The results form the input for a demonstration installation that will start operating in 2022.

3

PHAREM FILTRATION SYSTEM FEASIBILITY STUDY

The Pharem Filtration System is an innovative filter technology in which enzymes are used on a filter bed to break down organic micropollutants. Based on the results of this feasibility study, it can be decided whether or not to test the technology further in a pilot study.

The supplier of the technology has already done the necessary research, on lab, pilot and demo scale, but the technology has not yet been applied on the scale of a wwtp with a treatment capacity of 100,000 i.e. (inhabitant equivalents). The main goal of this research is therefore to collect pilot and/or lab data together with the supplier and to translate it to this level of scale.

Whether all prioritised micropollutants the so-called guide substances (see box) can be removed with enzymes will also be investigated. The results of this feasibility study are expected at the end of 2021.

RESULTS AND ONGOING STUDIES ALTERNATIVE ADSORBENTS

1

FEASIBILITY STUDIES (MODIFIED) SAND AND ZEOLITE AS ALTERNATIVE ADSORBENTS

These projects investigate the extent to which inert materials like sand and zeolite are capable of extensively removing micropollutants. Sand is now used in so called sand filters, which are capable of nutrient removal, but are not suited for removal of micropollutants. By modifying the sand through special slians, this might be possible too. Zeolite is now used in detergents. The question is whether it is possible for these zeolites, which end up in the sewer via the washing machine, to function as an adsorbent. Also the use of other synthetic zeolites in filters is researched. The results are expected early 2022.

2

FEASIBILITY STUDY USING CDP AS ADSORBENT

CDPs (cyclodextrin polymers) are a new class of adsorbents produced from corn. They have many potential advantages over activated carbon. An adsorbent has been marketed under the name DEXSORB®. The first test results from the US look promising, but more extensive testing and further translation to Dutch treatment practice is required. This is now ongoing in this feasibility study.

The feasibility study shows that the use of DEXSORB® in a filter is a sustainable alternative compared to the reference techniques: the CO_2 footprint is 2 to 5 times lower than that of the reference techniques. A wide group of guide substances are absorbed easily or very easily: anionic, cationic, zwitterionic, neutral and hydrophobic medicine and PFAS. Highly hydrophilic and small guide substances are removed less easily.

The resulting removal efficiency is 70 to 75 percent, which is comparable to PACAS and slightly lower than ozonation in combination with sand filtration. The treatment costs are also in the order of magnitude of ozonation in combination with sand filtration. Based on these results, especially in the field of sustainability, it was decided to conduct a pilot to further substantiate the results. This pilot will start in 2022.

OTHER STUDIES

1

INVESTIGATING NATURAL TREATMENT SYSTEMS

This project investigates the extent to which natural treatment systems are capable of extensively removing organic micropollutants. The systems under investigation are optimized helophyte filters that are already often used abroad for the removal of micropollutants. The difference compared to normal helophyte filters is that these systems are extra equipped for the removal of micropollutants by the addition of an adsorbent, fungi and/or other materials. This advances a combination of adsorption and biodegradation. The aim is to achieve the lowest possible CO_2 footprint by using materials with less fossil content. In addition, this project also examines possible optimisations of the water harmonica through a combination including ozonation. The research started in 2021 and the results are expected in 2022.

2

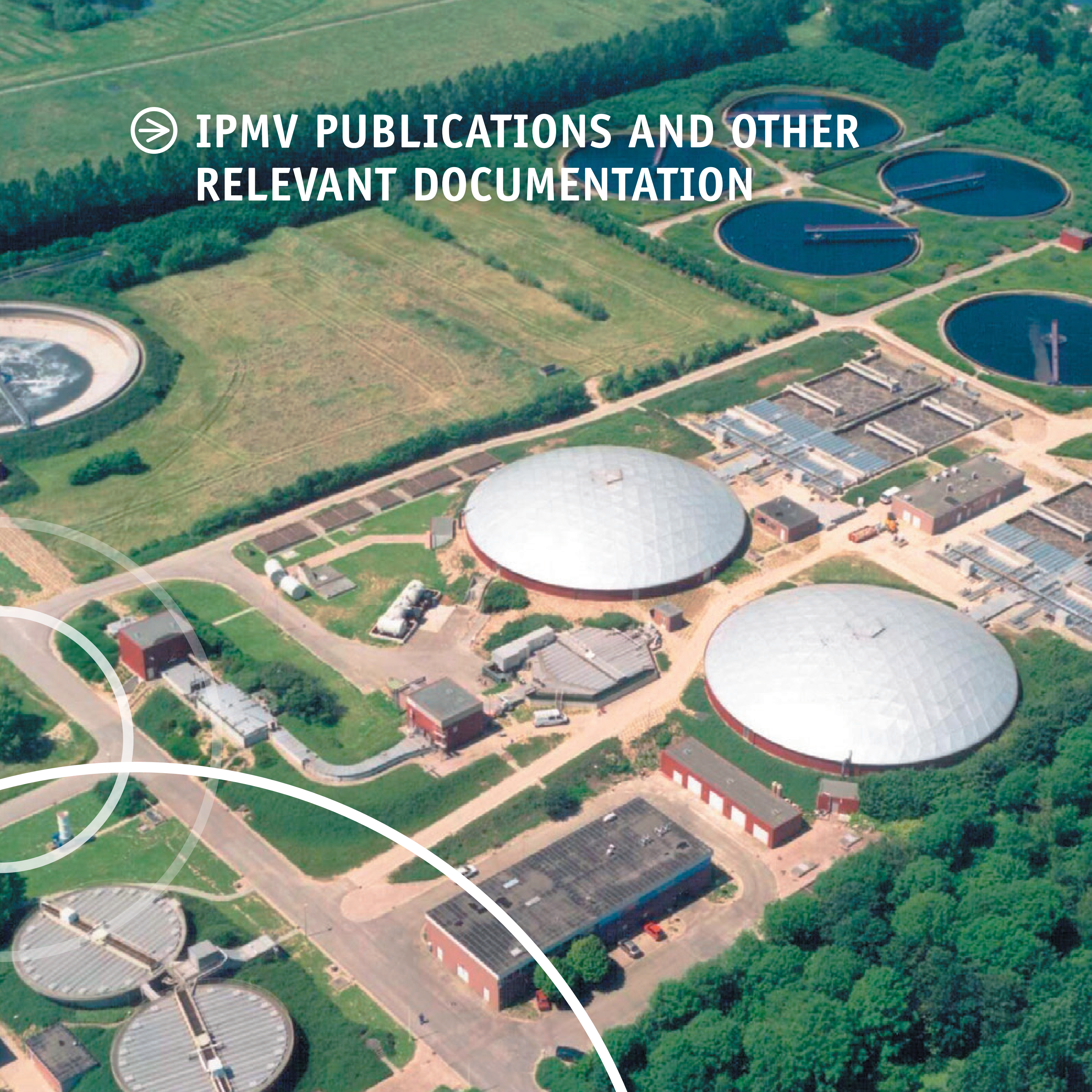
INVESTIGATING THE RELEASE OF MICROPOLLUTANTS IN SLUDGE DIGESTION

The aim of this project is to determine to what extent (bound) organic micropollutants are released again during sludge digestion and to what extent this influences the removal efficiencies of micropollutants by a wwtp.

If micropollutants are released in the digestion process, they end up in the so-called rejection water (water released from sludge dewatering). This rejection water is returned to the regular treatment process in the wwtp. If the load of micropollutants in this rejection water is high, this can negatively affect the removal efficiency of the wwtp and thus influence the dimensioning of additional treatment techniques.

In this project all different applications of fermentation in the Netherlands will be researched: mesophilic, thermophilic and Thermal Pressure Hydrolysis (TDH). The extent to which central sludge processing plays a role is also being examined; the more sludge that is processed centrally at a wwtp, the more micropollutants that could be released. In addition, attention is paid to the role of powdered carbon that is added to sludge. Does this powdered carbon in the digestion process cause the release of less or more micropollutants? The project started in 2021, the results are expected in mid-2022.

IPMV PUBLICATIONS AND OTHER RELEVANT DOCUMENTATION



You can read more about all the publications below at www.stowa.nl, where these reports can be downloaded. Use the search option on the website. The reports are in Dutch.

STOWA 2017-36, Assessment technological possibilities for removal of medicines from wastewater

STOWA 2017-42 National hotspot analysis of wwtps medicines

STOWA 2018-02, PACAS Powdered Activated Carbon in Activated Sludge - Research on efficiency and effectiveness at wwtp Papendrecht

STOWA 2018-46, Water Factory wwtp De Groote Lucht. Pilot research ozonation and sandfiltration

STOWA 2020-06, Removal of Organic Micropollutants. Guides for the choice of treatment technique in combination with the required hydraulic capacity

STOWA 2020-17, Feasibility of the Arvia Nyex™ technology: a treatment technique for the removal of micropollutants at sewage treatment plants

STOWA 2020-18, Feasibility study O3-STEP® filter

STOWA 2020-19, Feasibility study sustainable alternatives powder activated carbon for PACAS

STOWA 2020-20, Feasibility study powdered carbon dosing in Nereda for removal of micropollutants at wwtp Simpelveld

STOWA 2020-21, Feasibility study PAH+ screen filtration for removal of micropollutants at wwtps

STOWA 2020-22, Hollow fibre nanofiltration for removal of micropollutants at wwtps

STOWA 2020-23, Feasibility study PAC-O3 for removal of micropollutants at wwtps

STOWA 2020-24, Feasibility study Ultrasound in combination with ozone technology for the removal of micropollutants at wwtps

STOWA 2020-25, Feasibility study Healthy water

STOWA 2020-34, Powdered carbon in sludge. Effect on current and future sludge final treatment

STOWA 2020-41, Pilot study comparing oxidative techniques effluent wwtp Aarle-Rixtel

STOWA 2020-46, Feasibility Study BODAC. Biological activated carbon filtration with oxygen dosing for removal of micropollutants from wwtp wastewater

STOWA 2021-15 A to F Determination efficiency of removal of medicine residues from wwtp wastewater. Umbrella regulation and substantiating final report plus sub-reports

STOWA 2021-24, Laboratory tests for sustainable alternatives to activated carbon

STOWA 2021-36, Feasibility study upflow GAC Filtration

STOWA 2021-37, Feasibility study PACAS combined with dosing iron metal salts

STOWA 2021-38, Feasibility study DEXfilter: innovation in new adsorbents

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COLOPHON

Amersfoort, oktober 2021 © STOWA

Publication

Stichting Toegepast Onderzoek Waterbeheer STOWA
Postbus 2180
3800 CD Amersfoort
The Netherlands

Author

Bert-Jan van Weeren, tekst en van weeren

English translation

David Philo, Philo editing

Final editing

Mirabella Mulder, Cora Uijterlinde

Design	Shapeshifter.nl | Utrecht
Illustration	Adobe stock, Freepic
Press	DPP | Houten

STOWA-number 2021-45
ISBN 978.90.5773.954.5

Download

This brochure is available as a PDF at www.stowa.nl
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