Feasibility study
Feasibility of in-line coagulation for DOC removal at Andijk III WTW, The Netherlands
7 December 2019
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Introduction

The Andijk water treatment works (WTW) of PWN in North Holland has been expanded and upgraded over the years to improve finished water quality. For example, in recent decades, ultraviolet (UV) light irradiation with peroxide as an advanced oxidation process (AOP) and downstream biological granular activated carbon (BAC) were added downstream of conventional coagulation and filtration.

In 2014, a new treatment facility began operation, Andijk III. The new treatment train included suspended ion exchange (SIX®) followed by ceramic membrane filtration. The ceramic microfilter was selected because it provided a more robust filtration barrier, when compared to the conventional sand filter options. To combat fouling of the ceramic membranes during filtration cycles, ion exchanged was investigated because of its ability to remove dissolved organic carbon (DOC), which was recognized as a contributor to membrane fouling. The SIX® process effectively removes approximately 45 to 50 percent of the DOC; however, the water quality has been changing over recent years. The main change has been that more of the biopolymer organic fraction of DOC is present than before, and this contributes to membrane fouling.

Coagulation is effective for biopolymer removal, and this can be applied as in-line coagulation (ILCA®) upstream of the membranes. ILCA® installation on a full-scale is being investigated for the Andijk III WTW, and this feasibility study presents the advantages and disadvantages, as well as the overall feasibility of implementation to improve the membrane performance.

Challenges with DOC

DOC in source waters for drinking water plants poses many challenges to water utilities. Historically, DOC was noticed and recorded as colour, and customers could easily detect colour in their drinking water so utilities employed different treatments to remove that colour. These treatments were coagulation, with either aluminium or ferric-salt coagulants, oxidation with chlorine, chlorine dioxide, or ozone, or passing the water though a bed of activated carbon.

This colour, or DOC, was also found to consume chlorine or other disinfectants. This results in higher chemical application for these disinfectants, and this was ultimately found to be a health hazard, especially in the case when using chlorine, due to the formation of disinfection byproducts (DBPs). In recent decades, DBPs have become regulated in many countries, and this has led to an effort to remove or decrease the concentration of the main precursor to DBPs, DOC.

Coagulation with either aluminium- or ferric-salt coagulants was thoroughly evaluated, and researchers found that the coagulation process could be “enhanced” to remove the maximum amount of the DOC as possible. With this emphasis on DOC removal, other processes were also evaluated, such as adsorption onto granular activated carbon (GAC) or ion exchange (IX).

DOC was also found to interfere with processes that target other compounds, such as micropollutants.

DOC is preferentially removed by GAC over micropollutants, such as pesticides, so it is beneficial to remove DOC upstream of GAC at these installations. Also, DOC lowers the efficiency of UV and AOPs for disinfection and micropollutant oxidation.

DOC was also found to affect membrane treatment processes, which were being installed more frequently, starting in the 1990s, with a new focus on pathogens (e.g., *Cryptosporidium and Giardia)* that can sometimes pass through sand filters. Early membrane installations were with polymeric fibers, and when fouling occurred, turbidity or suspended solids were thought to be the main issue. Over time, it was recognized that DOC was likely a more significant contributor to membrane fouling, and efforts to control DOC upstream of membranes were investigated.

Background

This section provides some background information about the Andijk III water source, water quality, and treatment processes.

Description of source waters

The water supply to the Andijk III WTW is from Ijsselmeer, or Lake Ijssel. It is a shallow, man-made reservoir which is primarily fed by the Rhine River. There is a small, inner reservoir which holds about three days of water supply at the inlet location to the water plant. This small reservoir is hydraulically connected to Lake Ijssel; however this connection can be closed in the event of a water quality incident (e.g., spike of a pesticide or industrial discharge chemical concentration). This reservoir also allows for some pre-settling of suspended solids from the reservoir.

Historical water quality

As mentioned before, the nature of the DOC in Lake Ijssel has changed over time, with increasing concentrations of biopolymers being observed (see figure). It is thought that environmental factors are affecting the nature of the DOC.

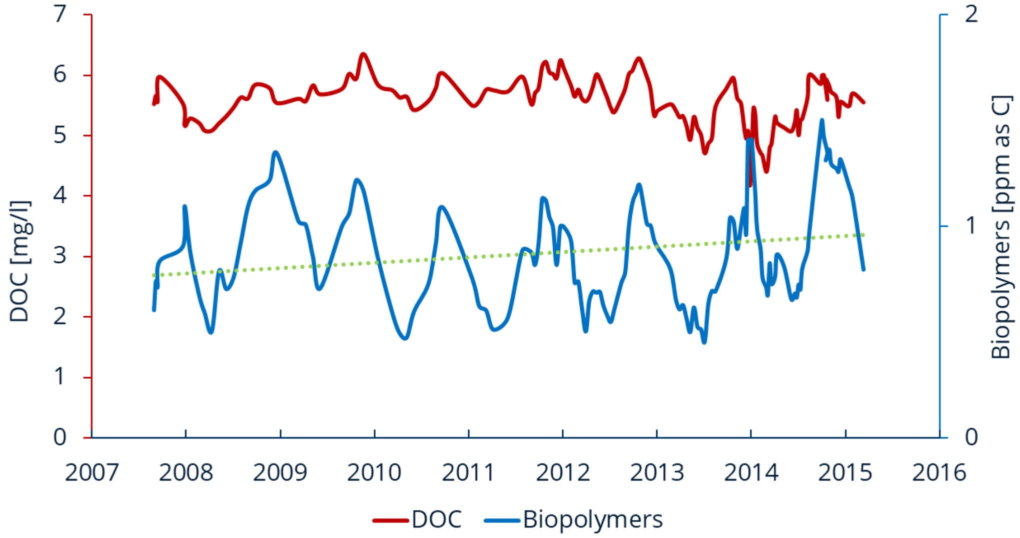

Figure 1. DOC and biopolymer concentrations in Lake Ijssel over time

Description of treatment processes

In May 2014, new pre-treatment at Andijk III was put into operation. The treatment train is shown in figure 2. First, water is dosed with sodium hydroxide (NaOH) prior to entering the reservoir, and then with carbon dioxide (CO_2) before being screened (200 micron).

Next, the water enters the SIX® process, where resin is dosed before the five-stages of contactors. Resin is settled from the process in a lamella settler, and the resin is collected and regenerated with salt before being returned to the head of the SIX® contactors. Hydrogen peroxide (H_2O_2) is dosed upstream of the CeraMac® microfiltration ceramic membrane filtration process. To clean the membranes, a low pH solution with H_2O_2 is used in some enhanced backwashes and a chlorine solution is used for other enhanced backwashes. Water then travels to the ultraviolet (UV) irradiation process, which performs as an advanced oxidation process (AOP) due to there being a H_2O_2 residual before entering the UV reactors. The water then passes through about 15 minutes of contact with biologically active carbon (BAC) before being dosed with a low concentration of chlorine dioxide (ClO_2) and then screened. Water is then sent to distribution.

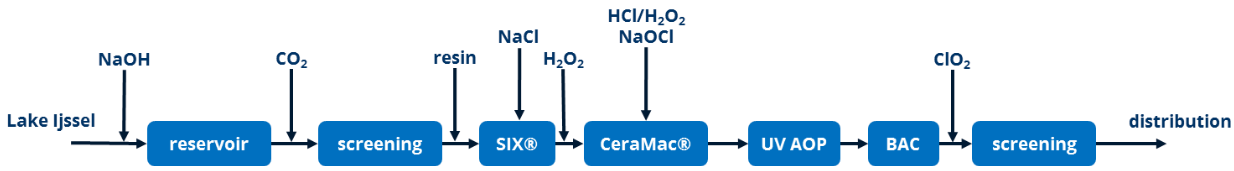

Figure 2. Process flow diagram of the Andijk III water treatment plant

<u>Description of in-line coagulation and adsorption</u>
In-line coagulation and adsorption (ILCA®) is a treatment step that allows for the coagulation and flocculation in a relatively short contact time, so that DOC can be captured on the coagulated hydrolysis products, and ultimately the formed flocs, prior to membrane filtration.

The process generally includes pH adjustment, with either an acid or base, to achieve the optimum pH for the coagulation of DOC with the chosen coagulant. Aluminium sulphate (alum), aluminium chlorahydrate (ACH), and polyaluminium chloride (PACl) are commonly used, but ferric-based coagulants, like ferric chloride and ferric sulphate are also possible. The coagulant is mixed thoroughly with a static mixer and then the water enters the ILCA® tower.

The ILCA® tower has specially-designed baffles to yield flocculation conditions for floc development. The current practice is to use approximately two minutes of contact time in the ILCA® tower. It is also possible to provide the flocculation in a pipe flocculator; site conditions and restrictions may dictate if a tower or pipe flocculator is most suitable. Water from the ILCA® tower then goes to the ceramic membranes.

The DOC removal that can be achieved by ILCA® is dependent upon the coagulation conditions, such as pH, coagulant dose, coagulant type, etc. Jar tests often show the dose and pH that can be used full-scale for optimized DOC removal. Optimizing DOC removal oftentimes coincides with optimum conditions for ceramic membrane filtration, because if DOC is controlled with coagulation, it is less likely to caused elevated rates of fouling on the ceramic membrane.

It should be noted that traditional coagulation and flocculation has been used for decades for turbidity control, so that flocculated particles could be removed by sedimentation upstream of conventional sand filters. In the 1990s, with the new aims to remove DOC for control of DBPs, more study was performed to improve coagulation, with a defined "enhanced" coagulation which generally meant operating at a lower pH and perhaps with more coagulant to yield the most DOC removal while maintaining sufficient floc development.

In these evaluations, enhanced coagulation could yield as much as 50 percent DOC removal; however this was largely dependent on the type of organics in the source water and varied from plant to plant. For the ILCA®, enhanced conditions can also be achieved, but the floc development is less than a conventional flocculator because the ceramic membrane does not need a large floc to perform well. A pin floc is sufficient.

There in on-going research to better optimize coagulation for pre-treatment to ceramic membranes. This is conducted with both jar tests and pilot-scale studies. Researchers are investigating the zeta potential along with pH for optimized coagulation.

Feasibility assessment

During the DOC2C's project, ILCA® was investigated for possible implementation at the Andijk III facility. Since 2014, the membranes have experienced some periods of elevated fouling rates and the warmer and sunnier summers than past years have caused the organics character in the Lake Ijssel to change.

Pilot-scale evaluation

Pilot-scale evaluations of ILCA® were conducted in the R&D facility in Andijk, under critical conditions using an already fouled membrane with low permeability. Filtration settings were identical for the two different set-ups, with and without ILCA®, specifically flux 80 $l/m^2/h$, filtration load 49 l/m^2, 10 normal backwashes follow by enhanced backwash alternatively acid and alkali. The ILCA® process was obtained by addition of $FeCl_3$ coagulant and pH corrected at 7.7. Operational results were evaluated in terms of transmembrane pressure (TMP) development in time and in terms of fouling rate (FR) namely angular coefficient of the linear regression of the TMP data. The operational results with and without ILCA® are reported in Figure 3.

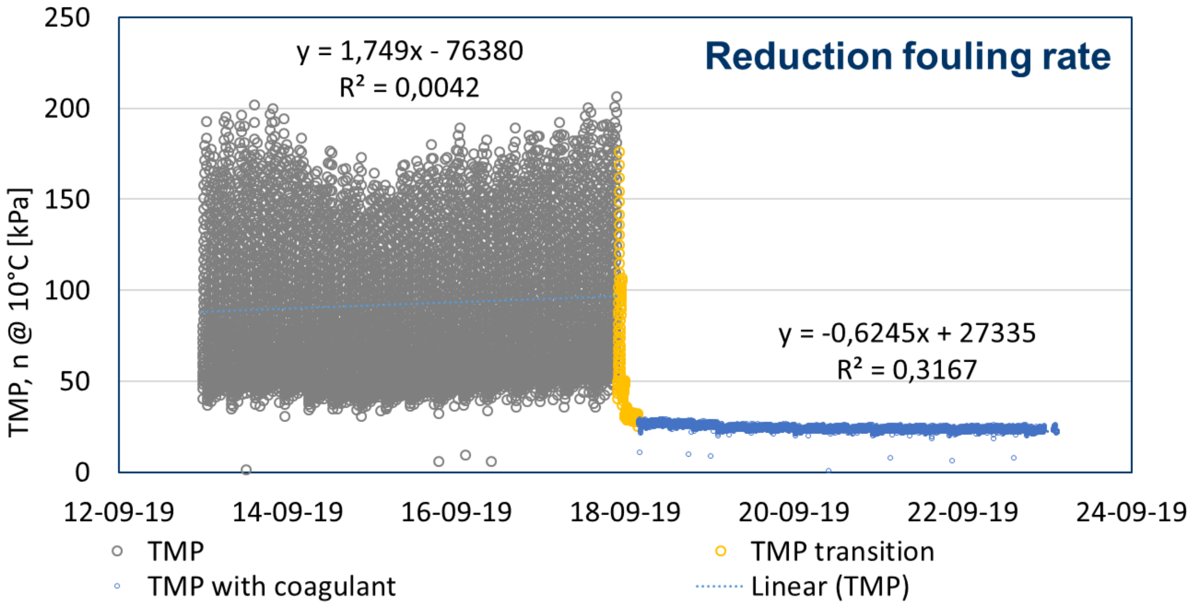

Figure 3. TMP development in operation without (left) and with ILCA® pretreatment using ferric chloride at pH 7.7

Because of the low permeability conditions of the membrane, the TMP during operation without ILCA® (grey data set of Figure 3) was substantially high, approximately ranging from 40 up to 200 kPa. Under these conditions the fouling rate resulted in 1.7 kPa/day. After starting up the ILCA® process a sharp reduction of TMP was observed (yellow data points of Figure 3). This transition phase occurred in a couple of hours. After the transition period, the operations stabilized (blue data set of Figure3) resulting in a TMP during filtration between 25 and 30 kPa with a neglectable fouling rate. This allowed to proceed with more testing with higher filtration flux and filtration load (Figure 4).

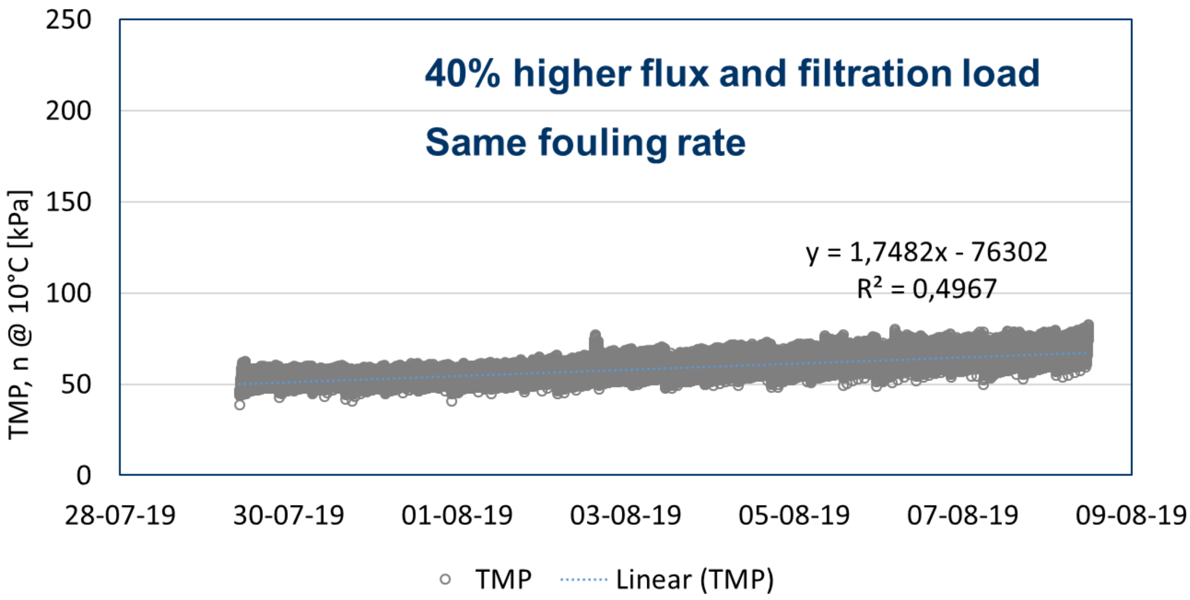

Figure 4. TMP development using ILCA® pretreatment to CeraMac® (flux 120 lmh)

At the filtration flux 120 $l/m^2/h$ and 70 l/m^2 filtration load operational performance were still sustainable with TMP ranging between 40 and 70 kPa and a fouling rate of 1.7 kPa/day. Comparing these results with the previous tests without ILCA®, a TMP reduction of about 80% which can be translated into an energy cost reduction of about 80%, was achieved while operating at an increased flux and filtration load (in other words, process productivity) of 40%.

<u>Demonstration-scale evaluation</u>

In 2018, a demonstration-scale ILCA® was installed at the Andijk III facility as pre-treatment to one CeraMaC® vessel (C90, with 90 membrane elements). Testing was performed with NaOH for pH control and with ferric chloride (Figure 5).

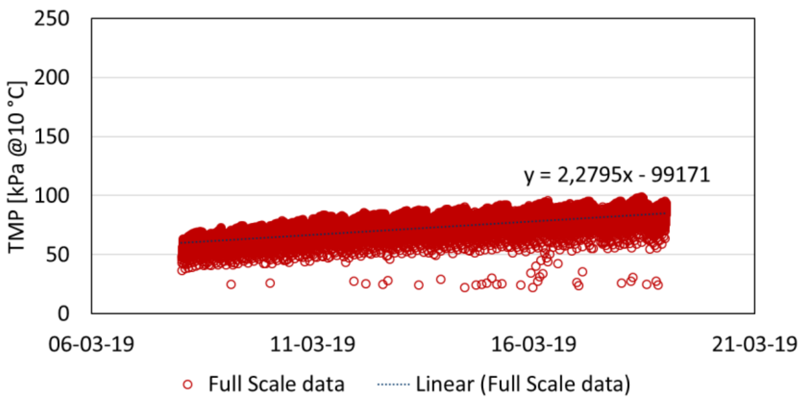

Figure 5. TMP development for the demonstration-scale evaluation of ILCA® pretreatment to CeraMac® (with ferric chloride coagulant)

The process was validated at full-scale and achieved approximately the same performance as the pilot testing.

System integration and footprint

The pilot- and demonstration-scale tests provided data to perform an evaluation of the integration and footprint of the ILCA® into the Andijk III water plant. This work in on-going to evaluate a retrofit of ILCA® into the Andijk III WTW. The main considerations are footprint, hydraulic profile, chemical feed systems, chemical mixing, ILCA® design, retention time requirement, and solids capture/disposal from the coagulant.

Summary of feasibility

During the DOC2C's project, the feasibility of an ILCA® pretreatment to the C90 CeraMac® filters at the Andijk III WTW was evaluated. From the pilot- and demonstration-scale results, ILCA® will provide many benefits:

- Up to 80 percent energy reduction in pumping costs,
- Up to 40 percent increased productivity, and
- Improved water quality due to the removal of other fractions of DOC that are captured in the coagulated flocs (resulting in less overall DOC in the water treated by downstream processes of UV and GAC, which means that they perform more efficiently and at a lower cost).

The disadvantages or challenges to implement in a retrofit include:

- A coagulant and pH control feed system need to be added to the WTW,
- Handling and disposal of the solids will be required.

The next phase of this feasibility evaluation is in designing the system and further testing to optimize the coagulation.

DOC2C's project: cross border and global dissemination

In this work, cross border and global dissemination are performed initially within the project team, which included researchers from the Netherlands, Belgium, France, and the United Kingdom. During the DOC2C's project, annual workshops were held at different locations, to broaden the dissemination of information from the project team. These workshops were attended by not only the observers for the project, but also outside regulators and a utility from Singapore. Presentations by researchers were made at international water or membrane conferences, thus further dissemination of the results was made.

Finally, this feasibility study will be showcased at the final dissemination workshop (Andijk, The Netherlands; 6 November 2019) and posted on the project's webpage: www.doc2cs.com.

Dissemination of results

Research that is summarized in this feasibility study, along with additional findings that were made during the four-year DOC2C's project have been disseminated in the following ways:

- This feasibility study was presented at the final dissemination workshop, where 48 persons were in attendance. These were a mix of water utility staff and operators, university professors/students, engineers, regulators, and equipment suppliers. It is anticipated that these attendees shared their experiences and newly gained knowledge from the workshops with colleagues where they work/live.

- The 2018 workshop at the Mayflower WTW introduced the 76 attendees to a full-scale, 90 Mld ILCA® system. Attendees were mostly from the UK and Europe, but also a utility in Singapore also attended and learned about ILCA®.
- This feasibility study is posted on the www.doc2cs.com webpage, for anyone to read or download.
- A presentation of preliminary findings was also made at the American Membrane Technology Conference in 2017. This paper and slides are available through normal literature search mechanisms (e.g., online libraries, libraries, etc.)

Incorporation of small-to-medium sized entities (SMEs)
In this study, the following SME's were involved:
- Prozee: construction of the first pilot-scale ILCA® units
- Logisticon: construction of the first demonstration-scale ILCA® units, as well as the coagulation control for the pilot-scale system.

Technology transfer
The transfer of technology occurred via:
- Annual workshops networking
- Dissemination workshop networking
- Website posting and information
- Collaboration with project partners and observers/interested parties
- Tours at own facilities to utility staff visitors university visitors, public visitors, engineering visitors, regulatory agency, and manufacturer visitors.
- Pilot testing at third-party locations of ILCA®, including in Scotland, Sweden, another test pilot in Andijk, NL, and in England. At each of these locations, during pilot operations, operators were trained about the ILCA®. Furthermore, there were tours to utility staff and interested parties at each location.
- At the moment, the Mayflower water plant has a 90 Mld full-scale ILCA®. This feasibility study for the Andijk III location benefited from the findings of the Mayflower start-up data. The lead partner is currently in discussions with several utilities who are interested in ILCA®, and pilot testing at these locations is planned.

Outputs for Project Specific Objective:
Increase technological innovation for DOC removal in drinking water production

No.	Project Outputs	Project Specific Results	Achievements
1	Feasibility studies based on pilot plant operational findings	Widespread dissemination of project research feasibility results to observers, DOC2Cs area, and globally to any interested entity, including less or non-scientific water industry professionals	Achieved (see previous dissemination discussion)
		Increased knowledge base on the applicability of the tested technologies, leading to reduction of overall R&D costs for water treatment	The feasibility study, presentations by LP at Andijk (and also by PP2 about ILCA® study at their installations on the project webpage, along with presentations by observers on the webpage) create a knowledge base from which others can learn and start their own evaluation. The R&D efforts of the DOC2C's project help other utilities plan and design for future installations, thereby reducing their potential R&D costs.
		Introduction and consideration of advanced technology applications in areas of low technological performance	ILCA® is recognized to save construction cost while achieving the same coagulation water quality. Also, the footprint of the process is much smaller than standard, conventional clarifiers. The results of DOC2C's can help utilities plan more advanced solutions to water quality and pretreatment challenges.
		Increased and more rapid introduction of the new technologies where feasible, leading to more efficiencies in water treatment and better water quality	While ILCA® was studied in Andijk in a demonstration-scale and reported on in this feasibility study, ILCA® was installed at PP2's Mayflower WTW and startup activities occurred in 2019. The research of DOC2Cs propels the viability of this technology, in that with a full-scale installation other utilities can

			visit the facility, learn about its performance, and plan with certainty for their own installations. The demo-scale plant highlighted in this feasibility study also gives more credibility to ILCA®, with a different coagulant and design configuration .
2	New validated innovative technologies for drinking water treatment developed/designed by partners	Innovative integrated techniques validated on a range of water sources	ILCA® was tested on a lake water in this feasibility study.
		Reliable, future-proof drinking water quality	Testing of ILCA® on a demonstration scale gives confidence that the full-scale installation would perform well. Issues with performance or design can be identified in the demo-scale and implemented.
		Significant reduction (ca. 30%) in formation of disinfection by-products	Not applicable
		Lower ecotoxicity, better public health	By installing ILCA® at Andijk III, downstream UV and GAC processes will perform more efficiently in removing micorpollutants; thus the water quality and public health is expected to be improved. The LP also has data from another pilot study showing that there is increased virus removal, thus better public health, when using coagulation along with ceramic membranes.
		50 to 90% reduction in chemicals use (half or less coagulants dosing and pH conditioning, lower mineralisation)	Comparing in line coagulation (only) with conventional coagulation in Andijk, there is about a 75% reduction of coagulant dosage (20-25 ppm at conventional plant versus 6 ppm for ILCA). As a consequence of that also sludge can have the same reduction ratio.

			The ILCA® coagulant dose is lower due to having SIX® upstream for DOC removal.
		Sludge formation reduced at least by half	Compared with conventional water treatment plant, there would be a reduction at the same ratio as the reduction of coagulant dosage (see above)
		Reduction in energy use of various steps	By installing ILCA® at Andijk III, downstream UV is expected to consume less energy due to the removal of DOC. This was not specifically measured due to flow blending downstream.
		Desalinated brine as raw material for agricultural purposes	Not applicable

Outputs for Project Specific Objective:
Rapid, large scale uptake of technological innovation through cross-border open testing facility

No.	Project Outputs	Project Specific Results	Achievements
3	Innovations from technology providers tested in the pilot facility of the partners	In order to promote the innovative power of technology providers, the partners open their facilities to test new relevant technologies for DOC removal. Tests will range from bench scale to integrated pilot scale. The results are difficult to predict at this stage, but they will aim at:	The innovation of ILCA® was tested by PWN with the demonstration-scale test at Andijk III.
		• Reduced energy consumption	• With ILCA®, the data showed an 80% reduction in energy use
		• Reduced chemicals use	• Not applicable
		• Reduced by-product formation	• Not applicable
		• Reduced waste	• With lower coagulant dose, as observed at ILCA® in Andijk, there is expected to be a similar reduction in sludge waste. This is offset however by the Andijk plant having SIX® upstream, which generates a humics-laden salt brine for disposal.
		• Better water quality	For Andijk, about the same DOC removal is achieved with or without ILCA, because of the biopolymer fraction.
		This output will also speed up market introduction for new water technologies.	The results of this study can serve as a basis for other utilities to consider ILCA® for their current or future water or wastewater treatment facilities. Having demonstration-scale and full-scale examples of the technology in use gives

			confidence and speeds up the implementation by others into the water industry.
4	Water samples from different end-users tested in the pilot facility of the partners	Demonstration of the latest technical innovations on different sources of surface water shall:	Not applicable
		• guide other water utilities to adopt the most suitable treatment, leading to rapid transition to high technology and expansion of the adequate infrastructure for water production	• Not applicable
		• speed up market introduction for the new water technologies	• Not applicable