



DESIGN AND IMPLEMENTATION OF UV/H₂O₂ TREATMENT IN A FULL SCALE DRINKING WATER TREATMENT PLANT

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ABSTRACT

The presence of pathogenic organisms and micro-pollutants has caused PWN to replace breakpoint chlorination by a-selective barriers in their surface water treatment plants. Feasibility of the application of UV/H₂O₂ for both disinfection and organic contaminant control was studied.

The UV/H₂O₂ process treats pre-treated IJssel Lake water with a nitrate content of 6-12 mg/L and a DOC concentration of approximately 2.5 mg/L. To meet disinfection criteria for target micro organisms such as viruses and protozoa, a germicidal UV-dose of 70 mJ/cm² is necessary. Target micro pollutants are mainly pesticides, endocrine disruptors and pharmaceuticals. The applied UV-dose for organic contaminant control by advanced oxidation is 600 mJ/cm²; the H₂O₂ dosage is 6 ppm. Applying advanced oxidation process conditions, results in superior disinfection.

Extensive research preceded the implementation. In historic research, no response in the Ames test was observed in UV treated water under disinfection conditions. For atrazine, the formation of primary metabolites was researched in both the disinfection and the oxidative regime. Pilot plant research on byproducts mainly focussed the oxidative regime. Produced byproducts are nitrite and biodegradable compounds (AOC).

Long term pilot scale testing of the UV/H₂O₂ process, followed by activated carbon filtration (EBCT 30 minutes), was performed to monitor the formation of these products. Formation of 100-300 µg/L nitrate and 100-150 µg/L AOC was observed. Biodegradation by the GAC filters reduced the AOC to 16-18 µg/L. Formed nitrite was completely re-oxidized to nitrate in the GAC filters.

The additional function of the activated carbon, decomposition of the residual hydrogen peroxide, was studied as well. The expected catalytic decomposition of H₂O₂ by activated carbon was confirmed. Depending on the characteristics of the activated carbon, 6-9 minutes EBCT were required to decompose the residual H₂O₂ below detection limit.

Available UV-reactors were optimized for disinfection purposes only, based on disinfection modelling and CFD. In this case, both the disinfection and the advanced oxidation process needed to be performed by the same UV-reactor. Trojan Technologies' existing disinfection models and CFD capabilities, combined with collaborative research effort and development of a kinetic model for the advanced oxidation process, resulted in an optimized reactor design.

Based upon the model calculations, a full scale UV-system was designed, constructed and implemented. The full scale UV/H₂O₂ installation treats pre-treated IJssel Lake water and is located before of the existing activated carbon filters (EBCT 30 minutes). The maximum capacity of the plant is 4,500 m³/h.

The full-scale UV/H₂O₂ installation is operational since November 2004 and the performance has been monitored since. Earlier pilot results were confirmed.

KEYWORDS

UV/H₂O₂, system validation, byproduct formation, full scale design

INTRODUCTION

PWN's treatment facility Andijk mainly treats IJssel Lake water originating from the river Rhine. In the raw water concentrations of organic micro-pollutants such as pesticides, endocrine disruptors and pharmaceuticals as high as 1.0 µg/L have been observed.

After almost 40 years of operation the water quality of wtp Andijk (figure 1) still complies with the EC and Dutch drinking water standards. Nevertheless an upgrade of the treatment process is introduced in view of the following aspects:

- avoidance of the use of chlorine for breakpoint chlorination thereby restricting the byproduct (THM) formation;
- introduction of multiple barriers against pathogenic micro-organisms such as Giardia and Cryptosporidium;
- introduction of a disinfection credit for treatment steps based on a 10^{-4} health risk;
- introduction of a general barrier against organic micro-pollutants such as pesticides, endocrine disrupting compounds, algae toxins and pharmaceuticals based on EC and Dutch standards and/or a health risk approach.

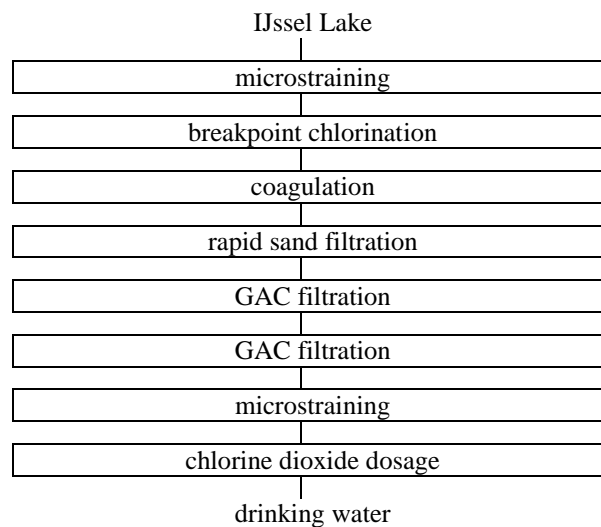


Figure 1: retrofit treatment scheme wtp Andijk (1978 – 2004)

Initially PWN investigated the suitability of O_3/H_2O_2 treatment for organic contaminant control. Although the results were very promising the process was not pursued in view of the bromate formation (up to 20 µg/L) in bromide rich (300 – 500 µg/L) IJssel Lake water. Consequently PWN has pursued UV/ H_2O_2 treatment for both primary disinfection and organic contaminant control.

October 2004, water treatment plant Andijk has been retrofitted for the second time since it was built in 1968. Originally, the treatment consisted of breakpoint chlorination, coagulation, rapid sand filtration and post-chlorination. The first modification, back in 1978, was the introduction of GAC filtration and post-disinfection with chlorine dioxide. Only recently, advanced oxidation by UV/ H_2O_2 treatment has been implemented for organic contaminant control and improved primary disinfection. Breakpoint chlorination is eliminated from the process. The UV/ H_2O_2 treatment is located just before the existing GAC filters.

TREATMENT OBJECTIVES

Disinfection

The disinfection requirements for the Andijk water treatment plant are based on an acceptable infection risk of 10^{-4} per person per year. Based on measurements in the IJssel Lake water the required inactivation for six index micro-organisms are calculated. (see Table 1).

Table 1: concentration of micro-organisms, disinfection requirement and required log removal

Micro-organism	Max. content IJssel Lake	Requirement	Total required inactivation	Inactivation pre-treatment	Inactivation required by UV
	n/L	n/L	log	log	log
E Coli	6000	10^{-2}	5.8	2.0	3.8
Faec. Strept.	3000	10^{-1}	4.5	2.5	2.0
Spores of SRC	4500	10^{-1}	4.7	3.0	1.7
Viruses	0.1	2.5×10^{-7}	5.6	2.0	3.6
Giardia	5.2	7.0×10^{-6}	5.9	2.5	3.4
Cryptosporidium	2.6	3.3×10^{-5}	4.9	2.0	2.9

The totally required inactivation amounted 4.5 – 5.9 log units, from which 2.0 – 3.0 log units were achieved by the conventional pretreatment steps coagulation and rapid sand filtration. Therefore 1.7 – 3.8 log units should be achieved by the UV treatment.

Literature data showed that the required UV dose for 3 log inactivation of most micro-organisms was in a realistic range ($< 120 \text{ mJ/cm}^2$). However, based on in vitro experiments, the dose needed for a 3 log kill of Cryptosporidium amounted 8600 mJ/cm^2 . This picture changed completely by the results of Clancy et al and Craik et al. Based on in vivo (mouse infectivity) experiments the dose needed for a 3 log inactivation of Cryptosporidium was as low as 16 mJ/cm^2 , much lower than the dose for Adenovirus 40 and Spores of Sulfite Reducing Clostridia. The data of Craik and al for Giardia muris and Cryptosporidium parvum are presented in figure 2.

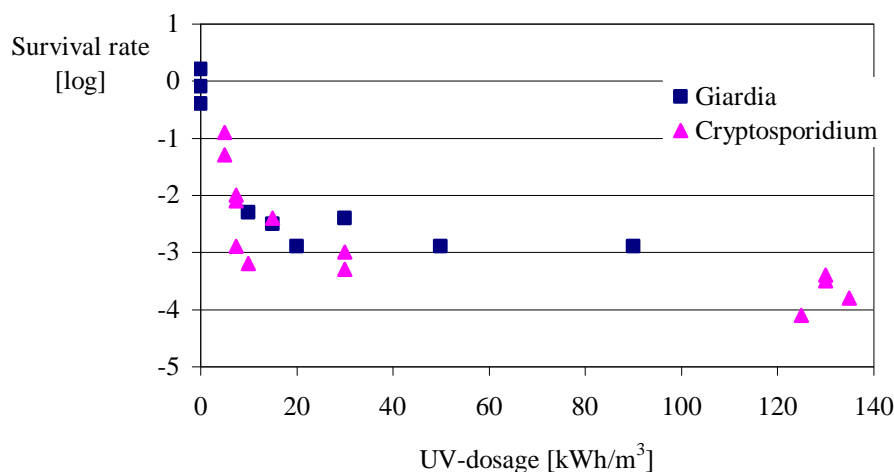


Figure 2: inactivation of Giardia muris and Cryptosporidium parvum by medium pressure UV radiation (Craik et al)

PWN considered the perspective of UV-light for the primary disinfection of surface water very promising. In a collaborative study with the University of Alberta⁽³⁾, UV dose-inactivation curves for MS2 phages, Giardia muris cysts and Cryptosporidium parvum oocysts have been established, using a bench scale collimated beam apparatus and a small scale medium pressure UV-pilot reactor.

Organic contaminant control

In the Netherlands approximately 350 pesticides with a great variety in persistence, degradability and toxicity are used. Monitoring programs have shown the presence of many of these pesticides in drinking water sources such as the IJssel Lake. Priority pollutants such as atrazine, pyrazon, diuron, bentazone, bromacil, methabenzthiazuon, dicamba, 2,4-D, TCA and trichlorpyr are found in concentrations up to $1 \mu\text{g/l}$. For these compounds the standard of the EC and Dutch drinking water act must be satisfied. In view of the raw water concentrations the required degradation was set at 80 %.

More recently monitoring programs have been focussed on the presence of endocrine disruptors and pharmaceuticals. In the raw water sources up to several hundred nanograms per liter were found for bisphenol A,

diethylphthalate, diclofenac, ibuprofen, phenazone, carbamazepine and several antibiotics and X-ray contrast media. For these compounds no standards have been set at this moment.

UV/H₂O₂ treatment, a combination of UV photolysis and hydroxyl radical reactions was pursued for organic contaminant control. Some literature data for the quantum yield Φ and k_{OH} of a number of herbicides are summarized in table 2.

Table 2: literature data for Φ and k_{OH} of herbicides

Herbicide	Φ	$k_{OH} \times 10^9 (M^{-1}s^{-1})$
Atrazine	0.05 (254 nm)	2.4 – 3.0
2,4-D	0.0262 (254 nm)	2.3
Diuron	0.022 (254 nm) 0.014 (296 nm)	4.6
Isoproturon	0.045 (254 nm) 0.0045 (275 nm)	5.2
Simazine	0.083 (254nm)	2.9
TCA		0.06

Plotting these data in a simplified kinetic model for herbicide decay showed that 80 % degradation could be achieved under realistic conditions. PWN considered the perspective of UV light this time in combination with H₂O₂ dosage for organic contaminant control very promising. Partly in collaboration with Trojan Technologies Inc., three major objectives were pursued:

- to model degradation by UV photolysis and hydroxyl radical reaction for selected priority pollutants (pesticides, endocrine disruptors, pharmaceuticals);
- to predict and determine the ability of a medium pressure UV reactor to degrade those priority pollutants;
- to design a full scale UV/H₂O₂ system for both disinfection and organic contaminant control.

Post treatment

Three additional objectives were pursued to enable integration of UV/H₂O₂ treatment in the total treatment scheme:

- the removal of excess H₂O₂ by GAC filtration;
- the removal of AOC by GAC filtration;
- the removal of nitrite by GAC filtration.

INACTIVATION OF MICRO ORGANISMS

For primary disinfection the focus was on inactivation of viruses, *Giardia muris* and *Cryptosporidium parvum*. The bacteriophage MS2 has been shown to be relatively resistant to UV inactivation. A reduction of approximately 1 log-unit was achieved when MS2 phages, suspended in PWN water, was exposed to UV doses of 20 – 25 mJ/cm². (Figure 3)

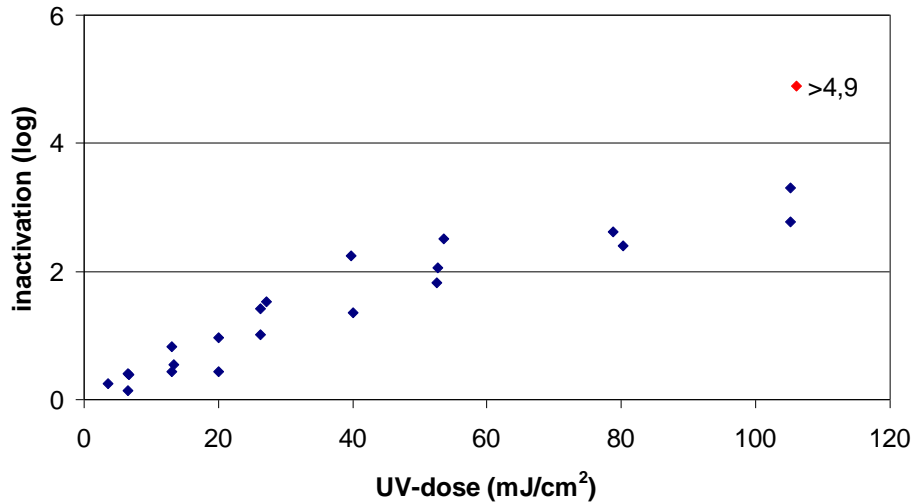


Figure 3: log inactivation of MS2 phages by UV disinfection

The correlation between log inactivation and effective UV dose demonstrated a near linear relationship, particularly within the UV dose range of up to 50 mJ/cm². This contrasts the UV inactivation curves obtained for *Giardia muris* (Figure 4) and *Cryptosporidium parvum* (Figure 5) where distinct shouldering and tailing effects were observed.

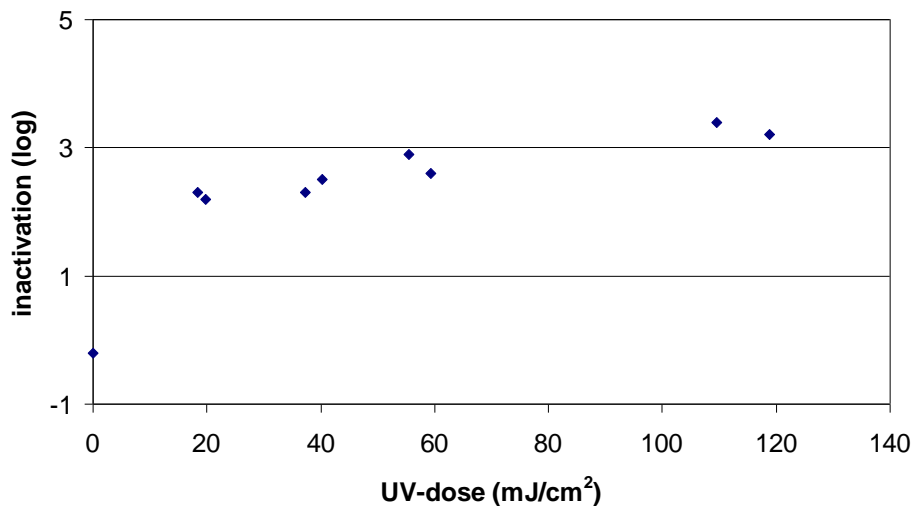


Figure 4: log inactivation of *Giardia muris* by UV disinfection

Exposure of *Giardia muris* cysts to UV doses as high as 120 mJ/cm² resulted in only 1 additional log-unit of inactivation compared to UV doses of 20 mJ/cm².

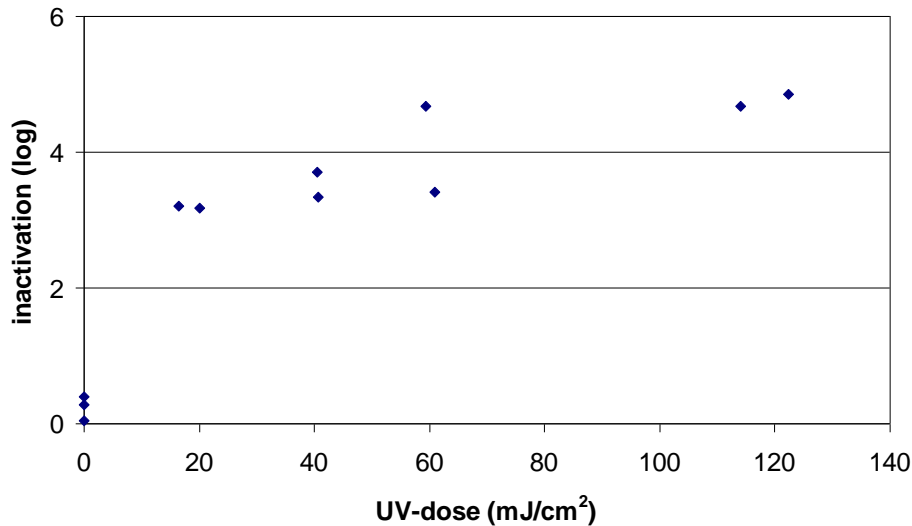


Figure 5: log inactivation of *Cryptosporidium parvum* by UV disinfection

Cryptosporidium parvum oocysts suspended in PWN water were extremely susceptible to low doses of UV. Greater than a 3 log-unit reduction in oocyst infectivity was observed in trials where oocysts were exposed to UV doses as low as 20 mJ/cm². For *Cryptosporidium parvum* oocysts the tailing effect of the UV dose-inactivation curve was not as pronounced as that observed for *Giardia muris* cysts (Figure x). UV doses of approximately 120 mJ/cm² induced greater than 4.5 log-units of inactivation.

The collimated beam data demonstrate that medium pressure UV radiation effectively inactivated MS2 phages, *Bacillus subtilis* endospores, *Giardia muris* cysts and *Cryptosporidium parvum* oocysts suspended in pretreated IJssel Lake water.

The established UV-dose inactivation relationships indicate a required UV-dose of 120 mJ/cm² to meet the inactivation criteria of the primary disinfection. The presented UV-dose for both the collimated beam experiments and the pilot experiments are not corrected for the absorption spectrum of DNA but represent effective UV-doses. The necessary UV-dose of 120 mJ/cm² equals a germicidal dose of approximately 70 mJ/cm².

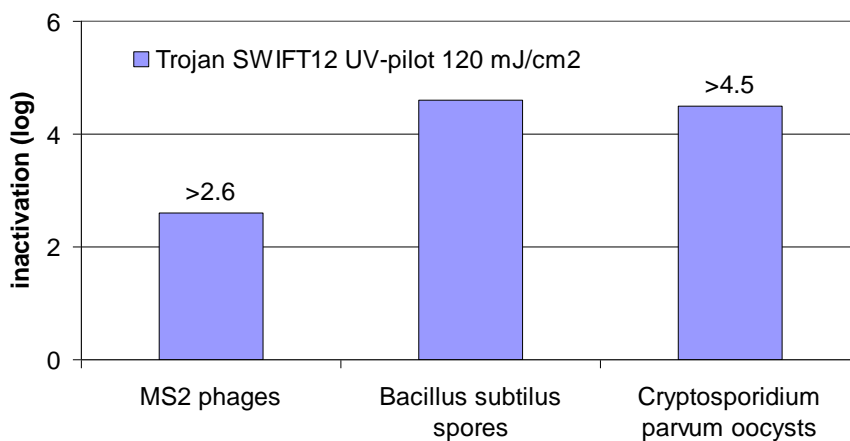


Figure 6: inactivation by UV of micro-organisms at 120 mJ/cm² (pilot data)

Inactivation of MS2 phage, *Bacillus subtilis* spores and *Cryptosporidium parvum* oocysts were studied on pilot scale (figure 6). Unfortunately, for MS2 phage, no exact inactivation could be determined due to a low influent concentration. The results for *Bacillus subtilis* and *Cryptosporidium parvum* confirmed the results of the collimated beam experiments.

The findings show that UV disinfection is a very reliable technology for the inactivation of pathogenic microorganisms in drinking water. An effective UV dose of 120 mJ/cm² gives a high inactivation of phages and endospores and a complete inactivation of protozoan cysts and oocysts.

Full scale virus data before and after implementation UV/H₂O₂

As determined at pilot scale, the required UV-dose for primary disinfection for the Andijk situation is 120 mJ/cm². Standard AOP conditions (540 mJ/cm²) result in superior disinfection. Regular microbiological analyses and large volume sampling have confirmed microbiological reliability but not resulted in the determination of an exact decimal elimination capacity for the retrofitted facility Andijk.

Presence of somatic phage in the IJssel Lake and inactivation of this virus indicator organism give an indication of the obtained decimal elimination capacity (DEC) for viruses. Table 3 presents the presence and reduction of somatic phage in IJssel Lake water and in finished water for the Andijk process with breakpoint chlorination and with UV/H₂O₂ treatment.

Table 3: presence and reduction of somatic phage (full scale data)

date	IJssel Lake (n/L)	effluent activated carbon filters (n/L)	DEC (-)
breakpoint chlorination			
1-21-2002	2342.0	0.0030	>5.89
2-20-2002	370.8	0.0034	5.04
3-13-2002	98.9	0.0036	4.44
4-3-2002	147.1	0.0039	>4.58
UV/H₂O₂			
1-31-2005	247.9	0.0019	>5.11
3-14-2005	404.5	0.0019	>5.34
4-27-2002	17.8	0.0038	>3.67
6-8-2005	18.3	0.0020	>3.96

After the introduction UV/H₂O₂ treatment a maximum DEC of >5.34 was observed. In the process with breakpoint chlorination a DEC of 5.04 has been observed. More data will be gathered to determine the maximum elimination credit of the retrofitted treatment plant.

ORGANIC CONTAMINANT CONTROL

Feasibility of the UV/H₂O₂ process has been also studied at the bench scale. Preliminary tests have been performed on synthetic water with similar characteristics as the pre-treated Lake IJssel water. Atrazine was removed to values lower than 0.1 µg/L at a UV-dosage of 0.5 kWh/m³, while no bromate formation could be observed at an energy input as high as 4 kWh/m³.

Research work was extended to pilot scale. For a selection of ten pesticides and one atrazine metabolite, the degradation by UV-photolysis as a function of UV-dose has been studied in a standard in line Berson reactor. The electric energy was ranging from 0.25 – 2.0 kWh/m³. All priority pollutants showed a significant degradation by UV-photolysis. The conversion for an electric energy of 1 kWh/m³ (about 1000 mJ/cm²) is summarized in table 4.

Table 4: pesticide degradation by UV-photolysis with 1 kWh/m³

Compound	Degradation (%)	Compound	Degradation (%)
atrazine	70	Dicamba	63
bromacil	42	2,4-D	58
pyrazone	52	TCA	18
diuron	65	Trichlorpyr	52
bentazone	50	Desethyldeisopropyl-atrazine	30
methabenzthiaxon	50		

By UV-photolysis with 1 kWh/m³, degradation ranged from 18 % for trichloroacetic acid (TCA) to 70 % for atrazine. The criterion of 80 % conversion had to be achieved by an additional H₂O₂-dosage to initiate a supplementary hydroxyl radical reaction.

The degradation of pesticides of interest by combined UV-photolysis and hydroxyl radical oxidation, for several peroxide-electrical energy combinations was studied. Examples for a compound with a high and a low UV-photolysis conversion are shown in figure 7 and 8.

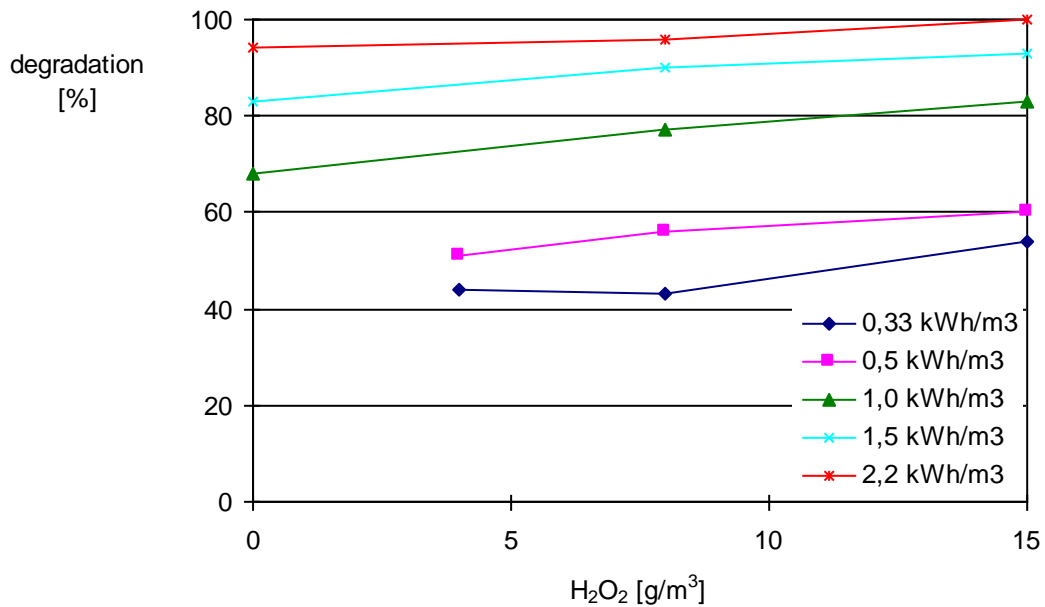


Figure 7: atrazine degradation by combined UV-photolysis and hydroxyl radical oxidation for UV-H₂O₂-treatment (pilot data)

Degradation of atrazine by an electric energy of 1 kWh/m³ amounted 70 %. This degradation was increased to the desired 80 % by adding 13 g/m³ H₂O₂.

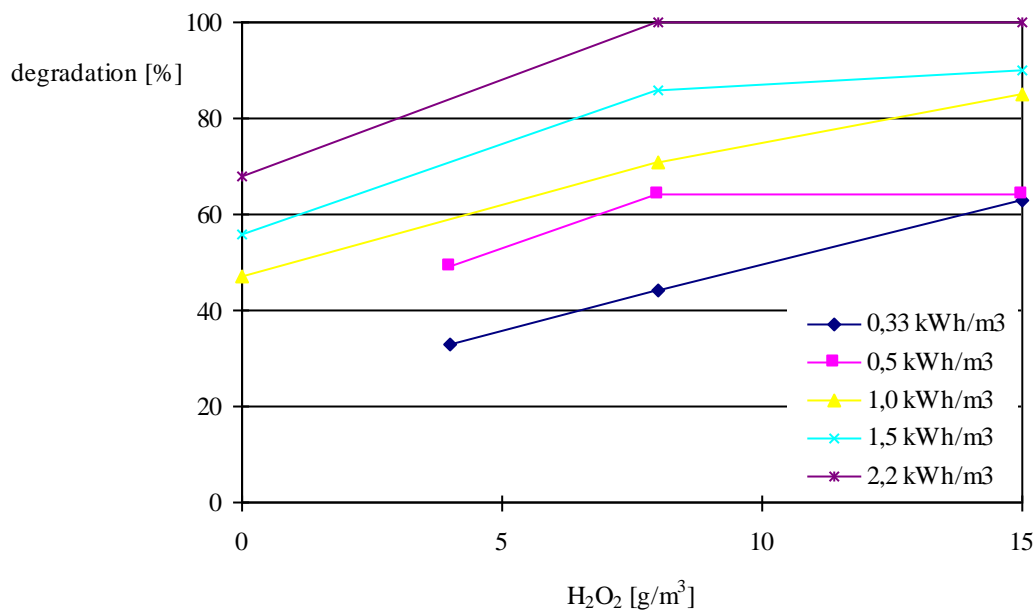


Figure 8: bromacil degradation by combined UV-photolysis and hydroxyl radical oxidation for UV-H₂O₂-treatment (pilot data)

Degradation of bromacil by an electric energy of 1 kWh/m^3 amounted 42 %. This degradation was increased to the desired 80 % by adding $15 \text{ g/m}^3 \text{ H}_2\text{O}_2$.

Depending on the UV molar absorption coefficients and quantum yields on the one hand and the chemical structure (double bonds, H-atoms) on the other hand, either direct photolysis or hydroxyl radical reactions play the predominant role.

In collaboration with UV-equipment supplier Trojan Technologies Inc., kinetic models for the dominant oxidation processes by UV/ H_2O_2 treatment, OH-radical oxidation and photolysis, have been developed. Extensive research on bench scale provided the kinetic parameters (quantum yield, rate constants)⁽⁵⁾. CFD-modeling in combination with the established kinetic models resulted in an UV-pilot reactor, optimized for organic contaminant control.

Figure 9 presents the dose-response relationship for atrazine degradation by UV/ H_2O_2 treatment. In this pilot UV-reactor ($20 \text{ m}^3/\text{h}$), under UV/ H_2O_2 process conditions of 0.56 kWh/m^3 and $6 \text{ mg/L H}_2\text{O}_2$, PWN's atrazine degradation target of 80% is achieved.

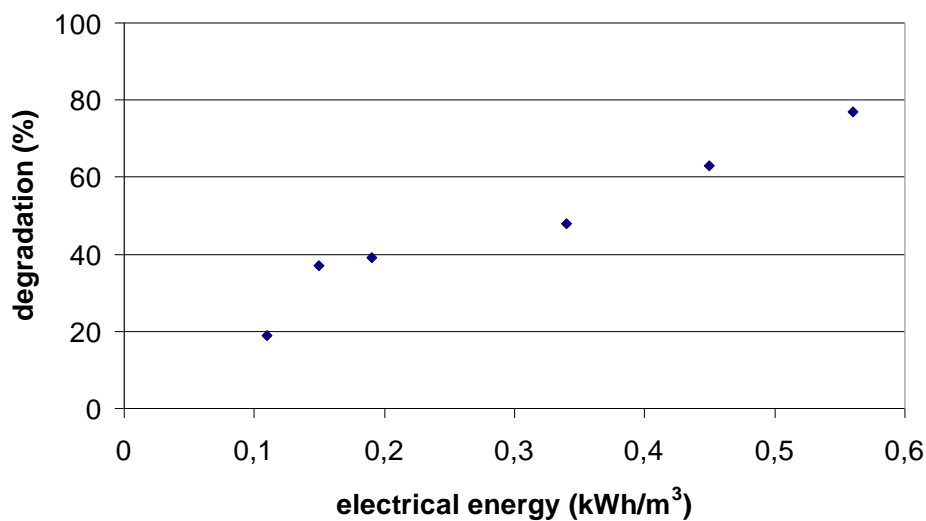


Figure 9: degradation atrazine as a function of the UV-dose in combination with $6 \text{ mg/L H}_2\text{O}_2$ (pilot data)

Predicted degradation for several organic micro-pollutants, for instance bromacil, was confirmed and refined in experimental work with the pilot reactor. Based on these results, a full scale UV-reactor was designed by Trojan and a reactor configuration and process conditions were proposed for PWN's treatment facility Andijk (0.56 kWh/m^3 and $6 \text{ mg/L H}_2\text{O}_2$).

Research into degradation characteristics of individual organic micro-pollutants, observed in IJssel Lake water, is ongoing. Figure 10 presents the degradation of solvent diglyme, figure 11 the degradation of anti epilepticum carbamazepine, both for process conditions at treatment facility Andijk, obtained in collimated beam experiments.

The major degradation mechanism for diglyme is hydroxyl radical oxidation. At standard operating conditions at Andijk, 600 mJ/cm^2 and $6 \text{ mg/L H}_2\text{O}_2$, 60% degradation is obtained. At maximum process conditions, 1200 mJ/cm^2 in combination with $15 \text{ mg/L H}_2\text{O}_2$, diglyme was degraded by 93%.

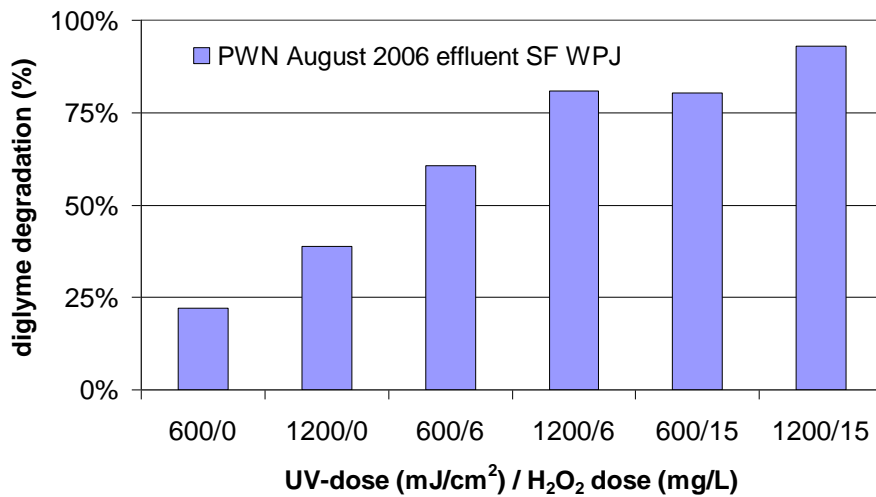


Figure 10: degradation of diglyme in bench scale experiments for relevant process conditions at Andijk

Degradation of anti-epileptic carbamazepine by UV/H₂O₂ was researched on pilot scale and in collimated beam experiments. Figure 11 presents the results of the collimated beam experiments for relevant process conditions. At standard process conditions for water treatment facility Andijk, 70% degradation is achieved. At maximum process conditions, 96% degradation was observed.

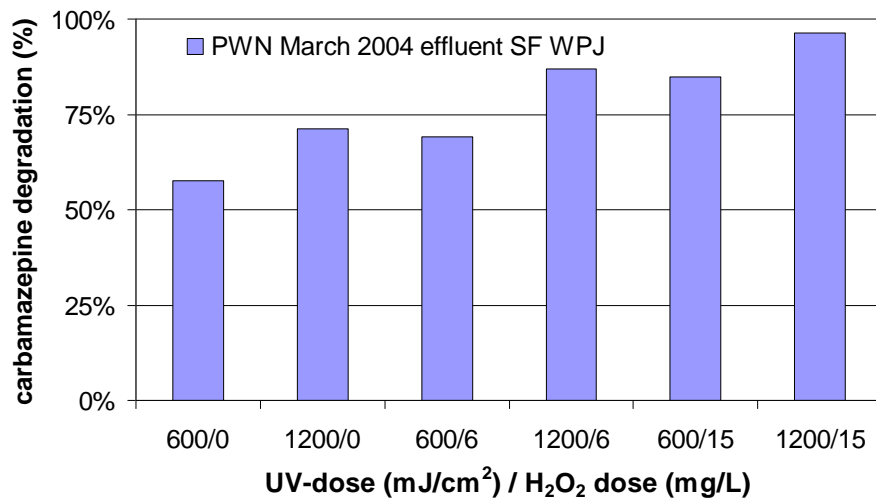


Figure 11: degradation of carbamazepine in bench scale experiments for relevant process conditions at Andijk

For several pharmaceuticals, the degradation under standard process conditions was studied (figure 12). The observed degradations in pilot plant experiments and bench scale experiments match well.

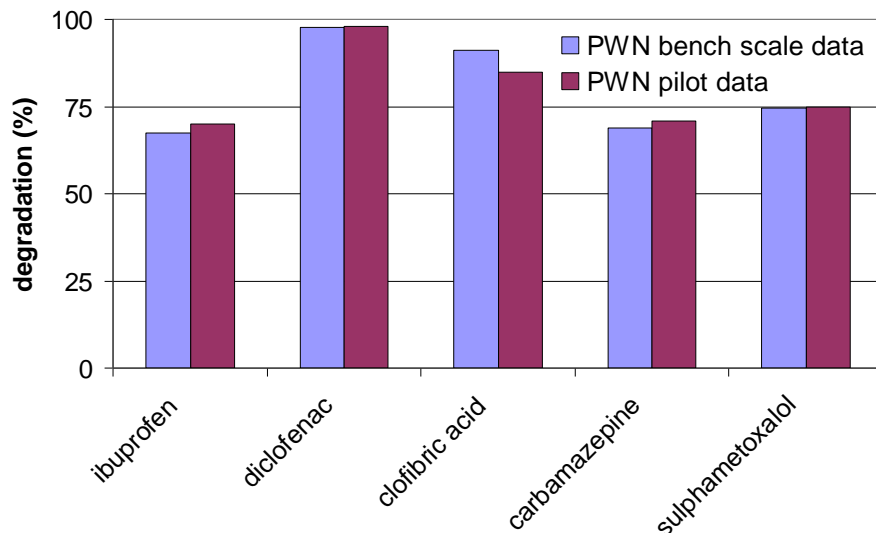


Figure 12: observed correspondence between degradation results for pharmaceuticals, obtained in both pilot plant research and bench scale experiments

The full scale UV- H_2O_2 equipment design is based upon kinetic models, refined and validated in pilot work and CFD-modeling. Design criterion for the UV/ H_2O_2 process step was 80% degradation of reference pollutant atrazine at 6 mg/L H_2O_2 and an electrical energy of 0.56 kWh/m³ (UV-dose 540 mJ/cm²). Upon startup of the retrofitted plant Andijk, a site acceptance test was performed at its design criterion.

For operating purposes, the UV/ H_2O_2 installation is equipped with a control-unit, calculating the atrazine degradation capacity under actual process conditions. In figure 13, this is referred to as ‘installation software’. Both for the ‘installation software’ as for the ‘kinetic model prediction’, the predictions presented were based on the actual water characteristics.

For testing purposes, one of the three full scale UV/ H_2O_2 production lines was isolated and spiked with atrazine and bromacil (~3 µg/L). Figure 13 presents the measured atrazine degradation referring to ‘experimental data’.

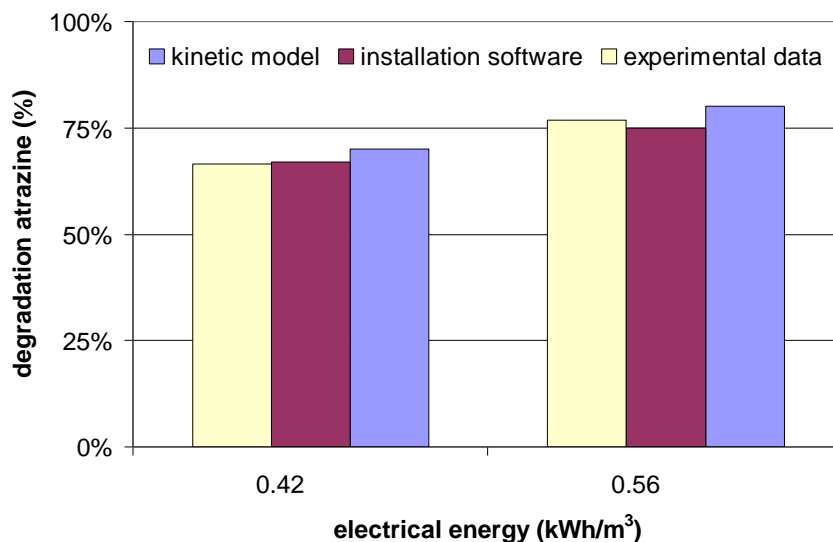


Figure 13: degradation of atrazine as function of the electrical energy with 6mg/L H_2O_2 (full scale data)

Process parameter electrical energy was set at two levels, 0.42 kWh/m³ and standard process condition 0.56 kWh/m³. It was found that within acceptance limits the measured degradation of atrazine was predicted by the installation software. Furthermore, good agreement was found, comparing the model calculations and the measured atrazine degradation in the full scale installation.

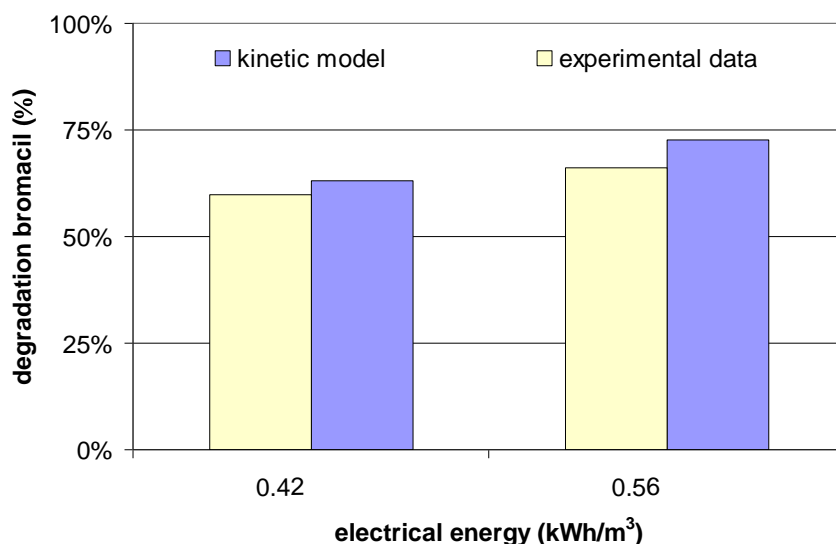


Figure 14: degradation of bromacil as function of the electrical energy with 6mg/L H₂O₂ (full scale data)

From collimated beam experiments and pilot work, it was known that atrazine is degraded predominantly by photolysis while bromacil is more susceptible to hydroxyl radical oxidation. These characteristics have been taken into account in the developed kinetic models. Figure 14 presents the agreement between the predicted degradation of bromacil in the full scale UV/H₂O₂ installation and the measured degradation during the site acceptance test.

Based upon the results of the site acceptance test, it was concluded that the full scale UV/H₂O₂ equipment met the design criteria.

After introduction of UV/H₂O₂, raw water and finished water have been monitored on the presence of organic compounds by GC-MS broad screening. This method is suitable for identification of organic compounds but has limited value to quantify concentrations.

In IJssel Lake water, 25 organic compounds have been identified (107 observations), after storage 22 organic compounds were found (84 observations). In finished water, this was reduced to 9 organic compounds (14 observations).

Flame retardant trichloropropylphosphate was identified 5 times in raw water and not detected in finished water. Detergent Surfynol 104 and plastic melamine were detected 11 and 7 times respectively in raw water and not detected in finished water. Anti-epileptic carbamazepine was detected 4 times in raw water and influent of the UV/H₂O₂. Carbamazepine was not detected in finished water.

Solvent diglyme was detected 8 times in raw water and 5 times in finished water. The observed degradation of diglyme by UV/H₂O₂ treatment in the full scale process was approximately 50% degradation.

Figure 15 presents the EDTA content in raw and finished water before and after introduction of UV/H₂O₂ treatment. After the introduction of UV/H₂O₂ per 2005, no EDTA is detected in finished water even with the high EDTA levels in raw water in the first half of 2005.

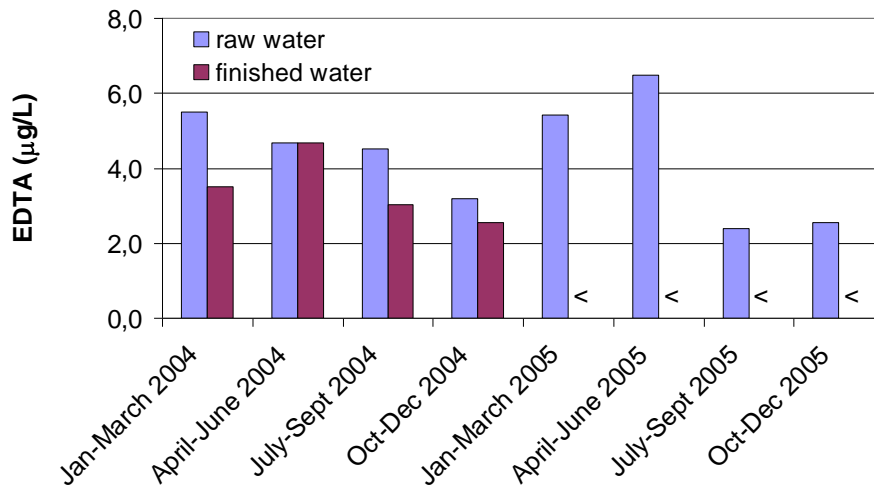


Figure 15: EDTA in raw and finished water before and after introduction of UV/H₂O₂ (full scale data)

Despite the limited full scale data, from the observed complete degradation of compounds such as EDTA and significant degradation of diglyme, it can be concluded that photolysis and oxidation processes take place at target level.

With the organic contaminant control and primary disinfection covered by UV/H₂O₂ treatment, the research focus shifted to long term testing of the UV/H₂O₂ process in combination with GAC filtration. GAC filtration is applied to enhance biodegradation of the oxidation reaction products, oxidize formed nitrite to nitrate and quench the residual H₂O₂.

POST TREATMENT

Nitrite

An important byproduct of medium pressure UV treatment is nitrite. Given the applied UV-dose of 540 mJ/cm² by this UV/H₂O₂ process, significant formation of nitrite takes place. Nitrification in biological GAC filters reduces the nitrite concentration below the EC-standard for nitrite (0.1 mg/L). The nitrite trend over the total pilot process is presented in figure 16. Experiments started with virgin GAC after the UV/H₂O₂. Similar to the existing treatment process at Andijk, empty bed contact time of the GAC pilot filters is 30 minutes.

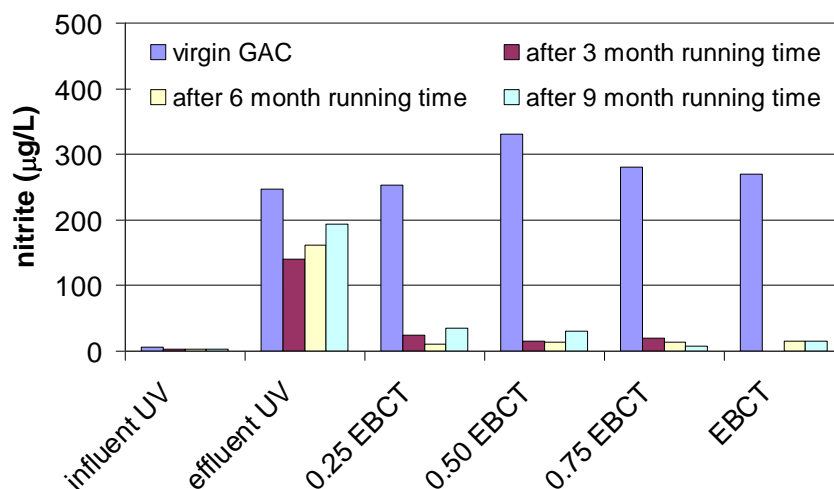


Figure 16: formation and degradation of nitrite for the UV/H₂O₂-GAC (pilot data)

Due to the absence of a microbiological population in the GAC filters, no significant oxidation of nitrite was observed during the first period of the running time with low water temperatures. With rising water temperatures, biological activity in the GAC filter increased.

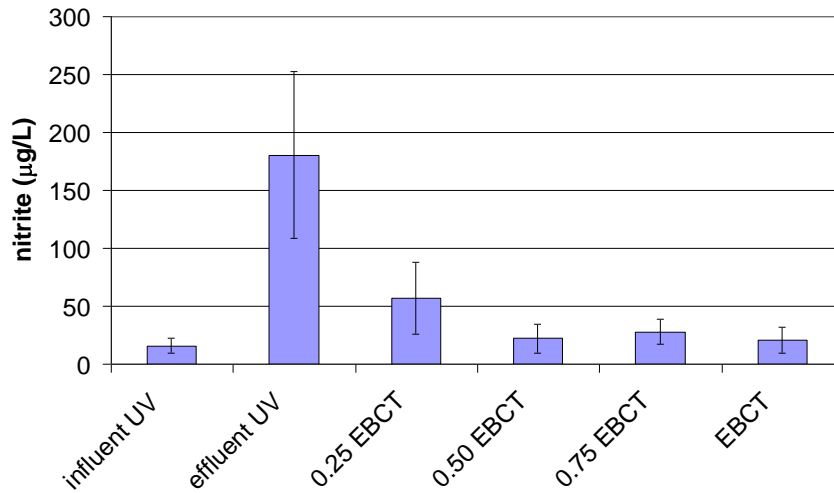


Figure 17: formation and degradation of nitrite (pilot data)

From the observed nitrite levels in the pilot scale process with matured biological GAC filters, it can be concluded that nitrification is not hampered by low water temperatures once the biological population is present (figure 17).

As observed in the pilot experiments, nitrite formation by medium pressure UV at the applied process conditions can be significant. Figure 18 presents the nitrite levels after the process steps ‘raw water’, ‘effluent UV’ and ‘finished water’ for the situation with breakpoint chlorination and for the retrofitted process with UV/H₂O₂ treatment in wtp Andijk.

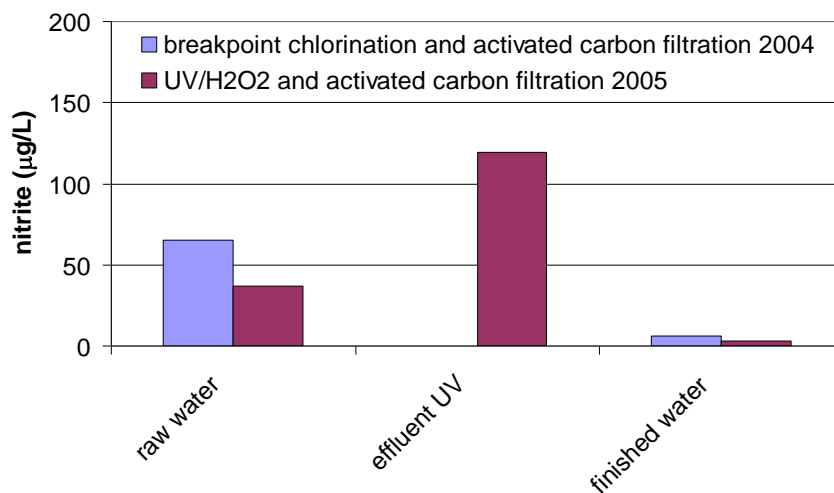


Figure 18: nitrite before and after introduction of UV/H₂O₂ treatment (full scale data)

As expected the nitrite content increased significantly by medium pressure UV. However, nitrite levels in the finished water have not been influenced by the introduction of UV/H₂O₂. There is complete nitrification of the nitrite produced by the UV in the GAC. The nitrite formation in the full scale UV/H₂O₂ installation appears to be marginally lower than the nitrite concentration, measured at pilot scale.

Biostability, AOC

Figure 19 presents the level of assimilable organic carbon through the process. AOC is a major parameter indicating the biological stability of water⁽⁶⁾. Advanced oxidation processes such as UV/H₂O₂ generate biodegradable organic acids from natural organic matter.

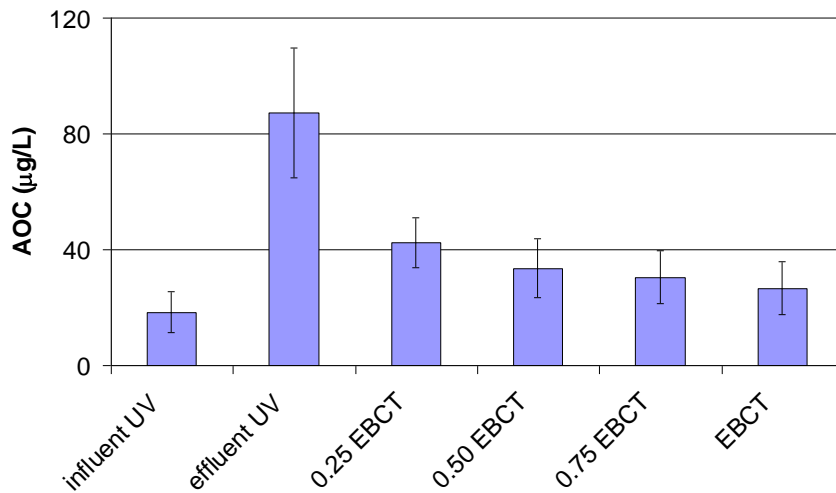


Figure 19: formation and degradation of AOC (pilot data)

The AOC increase by UV/H₂O₂ is reduced to a constant low level of approximately 20 µg/L in the post treatment with the biological GAC filters. In addition to AOC, the biofilm formation rate (BFR) was measured (see figure 20).

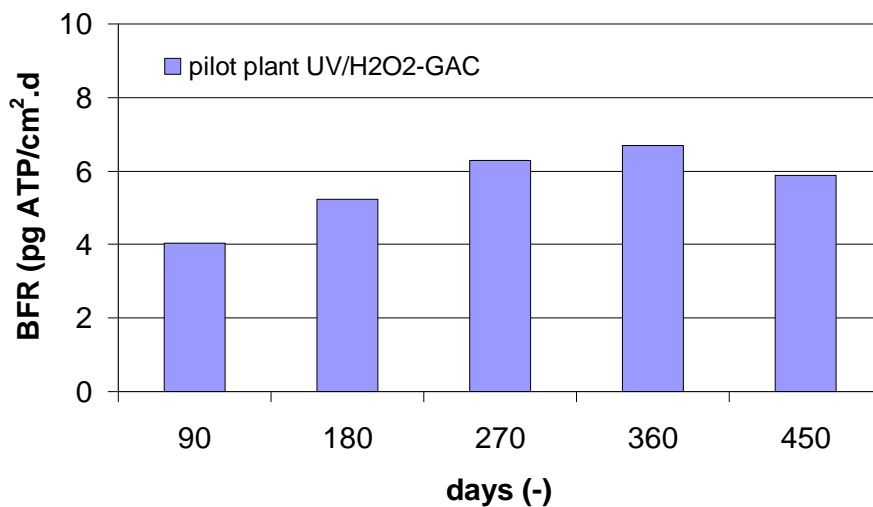


Figure 20: biofilm formation rate after UV/H₂O₂ treatment and GAC filtration (pilot data)

The average biofilm formation rate amounted 5.5 pg ATP/cm² day, indicating biological stability of the water after UV/H₂O₂ treatment in combination with GAC filtration.

After introduction of UV/H₂O₂ treatment in the full scale wtp Andijk, AOC in the effluent of the GAC filters was monitored. Figure 21 compares the AOC levels of activated carbon filtration effluent before and after introduction of UV/H₂O₂.

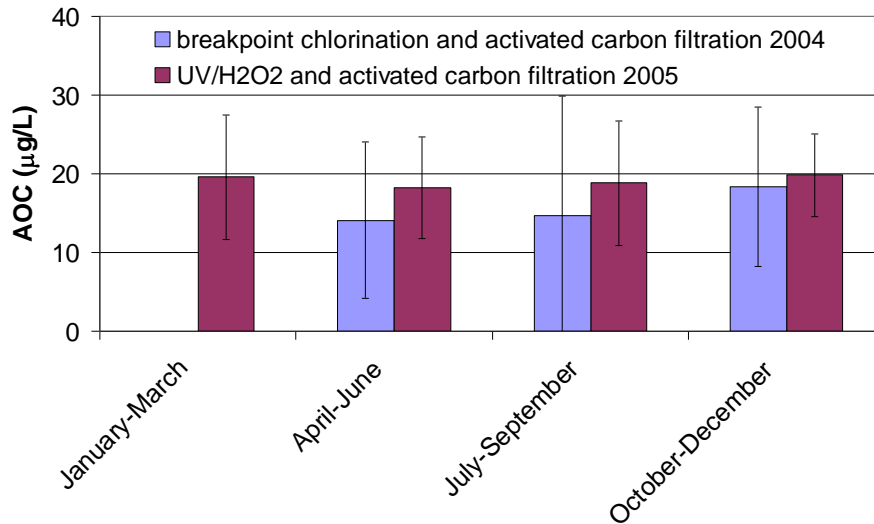


Figure 21: AOC after existing GAC filtration before and after introduction of UV/H₂O₂ (full scale data)

In figure 21, no significant increase of AOC with introduction of UV/H₂O₂ can be observed. These AOC levels are comparable to, or even lower than, the AOC levels measured in the pilot research. Based on this, the finished water produced by the UV/H₂O₂ retrofitted Andijk surface water treatment plant can be regarded as biological stable as it was before implementation of UV/H₂O₂.

Quenching H₂O₂ residual

For the formation of OH-radicals by the UV/H₂O₂ process, excess H₂O₂ is necessary. PWN standard process conditions require a H₂O₂ dose of 6 mg/L⁽⁴⁾. The residual H₂O₂ is quenched completely, in the first 8 minutes EBCT of the GAC filter (figure 22).

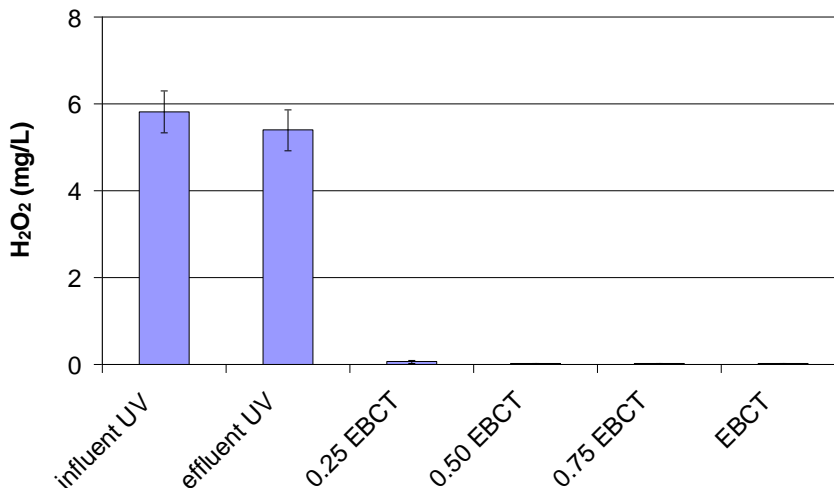


Figure 22: quenching of the residual H₂O₂ by GAC filtration (pilot data)

From a range of methods for quenching the residual H₂O₂, such as chlorination, sodium bisulphite dosage or catalytic quenching with metal oxides, for the specific PWN situation, application of the already existing GAC filters was selected.

EVALUATION

This paper describes the research and full scale application of the UV/H₂O₂-GAC process as nonselective barrier for organic contaminant control and primary disinfection at PWN's water treatment facility Andijk (20 MGD; 3000 m³/h).

Degradation target of selected reference pollutant atrazine (80% degradation) was reached in an optimized pilot UV-reactor at an UV-input of 0.56 kWh/m³ (~540 mJ/cm²) in combination with 6 mg/L H₂O₂.

Full scale testing proved that the UV/H₂O₂ installation meets the design criteria and degrades 80% atrazine at 0.56 kWh/m³ and 6 mg/L H₂O₂. Model calculations are confirmed by the performance of the full scale installation.

Collimated beam experiments with solvent diglyme resulted in 60% degradation under standard process conditions. In the full scale installation 50% degradation was observed, confirming the predicted performance of the full scale UV/H₂O₂ installation.

GC-MS screening on the raw water resulted in 22 organic compounds (84 observations). After UV/H₂O₂ treatment, only 9 different organic compounds were found (14 observations). Complexing agent EDTA was completely degraded by UV/H₂O₂ treatment.

Despite the limited full scale data, from the observed complete degradation of compounds such as EDTA, significant degradation of diglyme and the results of the GC-MS screening, it is concluded that photolysis and oxidation processes take place at target level.

To meet the inactivation criteria of pathogenic organisms *Giardia muris*, *Cryptosporidium parvum* and viruses for water treatment facility Andijk, a necessary UV-dose of 120 mJ/cm² was determined in bench scale experiments and confirmed on pilot scale.

Regular microbiological analyses and large volume sampling of the full scale process have confirmed the microbiological reliability and superior disinfection at standard AOP-conditions (540 mJ/cm²). After introduction of UV/H₂O₂ treatment, a maximum decimal elimination credit >5.34 for somatic phage has been observed.

For two years, the formation and degradation of byproducts such as nitrite and AOC in the UV/H₂O₂-GAC process were monitored on pilot scale. The average nitrite production was 150 µg/L. Nitrification in pilot GAC filters reduced the nitrite content to 25 µg/L.

In the full scale UV-installation, as observed in pilot research, a significant increase of nitrite content by medium pressure UV was measured. Due to nitrification in the biological GAC filtration, nitrite levels in the finished water have not been influenced by the introduction of UV/H₂O₂ treatment (<5 µg/L).

On pilot scale research, as a result of UV/H₂O₂ treatment, increase of AOC to approximately 85 µg/L was observed. After biological GAC filtration AOC-levels were reduced to 20 µg/L. AOC levels in finished water of water treatment facility Andijk before and after introduction of UV/H₂O₂ do not differ significantly. Observed AOC levels in UV/H₂O₂ pilot research after GAC filtration are comparable to the AOC levels in the full scale installation after implementation of UV/H₂O₂ treatment.

The residual H₂O₂ from the UV/H₂O₂ process is quenched in the first part of the biological GAC filter. It is observed that nitrification, AOC reduction and hydrogen peroxide quenching mainly take place in the first 8 minutes EBCT of the GAC filter.

The successful implementation of UV/H₂O₂ as nonselective barrier against organic micro pollutants and primary disinfection step in combination with biological GAC filters at water treatment facility Andijk has resulted in a robust solution for the production of safe and reliable drinking water from surface water. PWN has decided to implement the UV/H₂O₂ process at her facility Heemskerk (40 MGD; 6000 m³/h) as well.

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