NEW TREATMENT SYSTEM PRODUCES CLEANER DRINKING WATER FROM THE MEUSE RIVER

Water Convention 2011 – Best Poster Winner (2nd Runner Up)

J. Scheideler, K. Lekkerkerker-Teunissen**, T. Knol**, A. Ried*, J. Verberk, H. van Dijk***;*
ITT W&WW (now Xylem Services), Dunea**, Delft University of Technology****

Dunea, the drinking water company for The Hague and surroundings, produces drinking water from the Meuse River and supplies over one million people in The Hague and its surroundings with drinking water. At the moment a full scale research installation, developed by Xylem (Formerly ITT) and Dunea is in operation.

This is a major milestone achieved by the joint Dunea and Xylem R&D team since they won the Best Poster Award in 2011 for their research into extending Dunea's multiple-barrier treatment with advanced oxidation processes (AOP) to remove organic micro pollutants, including pesticides. Results showed that combining ozone/H_2O_2 and UV could efficiently remove a broad range of target compounds, and at lower operational cost compared to a single AOP step. This research collaboration eventually led to the implementation of a full scale research system with a treatment capacity of 2,200 m^3/hr in 2016. It is currently undergoing final performance tests, and according to Dunea, will represent the first full-scale system using sequential AOP for potable water treatment in the world. The technology has been commercialised by Xylem and is now known as *MiPRO eco3 plus.*

Following the presentation of the poster at Water Convention 2011, Dunea's & Xylem's research was selected for publication in IWA's Water Practice & Technology journal (available at wpt.iwaonline.com/content/6/4/wpt20110063).

For Mr Jens Scheideler, the lead author of the paper in 2011 and Xylem's Global Reuse & AOP Manager, the future key trends in the water industry "will be to make water treatment smart through online sensors and controls, and machine learning to allow the most economic treatment and assure the production of compliant drinking water. Associated with that is the way towards direct potable reuse driven by the technology of online monitoring."

The abstract and poster submitted by ITT W&WW (now Xylem Services), Dunea and Delft University of Technology for the Water Convention 2011 have been included in this article for your reference.

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COMBINATION OF O_3/H_2O_2 AND UV FOR MULTIPLE BARRIER MICRO POLLUTANT TREATMENT AND BROMATE FORMATION CONTROL – ONE YEAR PILOT PLANT RESEARCH

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Keywords: Advanced oxidation; AOP; organic micropollutants; low pressure lamps; medium pressure lamps; ozone; bromate formation

Introduction
Dunea, the drinking water company for The Hague and surroundings, has as objective the production of drinking water of impeccable quality, particularly with respect to organic micropollutants. As organic micropollutants are only a minor part of the total natural organic matter, a challenge is posed in targeting the removal of a very small, specific part of the natural organic matter, without removing all of it. In addition, organic micropollutans (OMPs) encompass a broad range of physicochemical properties, which make their removal by one single treatment step almost impossible. Advanced oxidation process (AOP) can provide an effective barrier against OMPs. Different combinations of AOPs are available. The optimal solution for the removal of OMPs from a specific water type depends on removal requirements and the water matrix. Considerations can also involve existing infrastructure, such as pre- and posttreatment and available footprint. In this paper/presentation the results of one year pilot scale experiments with different combinations of AOPs are summarized.

Material and Methods
Pilot-scale experiments with different AOPs (UV/H_2O_2, O_3/H_2O_2 and $O_3/H_2O_2/UV$) were carried out in a pilot installation. A special designed ozone/peroxide reactor was used for the experiments with the scope to prevent the formation of significant Bromate concentrations. This device was than followed by a four lamp LP-UV reactor. The pilot installation had a capacity of 5 m^3/h, a LP-UV-dose of 300 – 650 mJ/cm2, an ozone dose of 0-5 mg/L and a hydrogen peroxide (H_2O_2) dose of 0-10 mg/L. The pilot plant was fed with Meuse river water, pretreated by coagulation/sedimentation, microstraining and dual layer rapid sand filtration. The UV-T (UV transmission at a wavelength of 254 nm) of the water varied over the year between 78-82%, the average DOC concentration was 4 mg/L, the average bromide concentration was about 100 µg/L. Bromide was incidentally spiked to see the influence of higher Bromide concentrations on the bromate formation trough the ozone treatment. Four model compounds, Atrazine, Bromacil, Ibuprofen and NDMA, were spiked and analyzed by UPLC.

Results and Discussion
Figure 1 shows the degradation results of the four model compounds during different AOP combinations and settings. Bromacil is completely removed with O_3/H_2O_2, already with a low dosage (1 mg O_3/L, not in figure). Atrazine and Ibuprofen are removed with O_3 dose of 2 or 3 mg/L. However, their removal is depending on the O_3 and H_2O_2 dose. NDMA is not removed by this AOP combination. NDMA does neither react with O_3 and only weak with OH radicals. Figure 2 shows the formation of Bromate during an experiment in which Bromide was spiked to the influent water until a concentration of 320 µg/L. An O_3 dose of 1 mg/L does not form significant Bromate. An O_3 dose of 2 or 3 mg/L resulted in Bromate formation. The Bromate formation was decreased when Peroxide was dosed. With these settings it was calculated that the combination of O_3 and H_2O_2 can provide a cost efficient barrier against a large group of OMPs with limited Bromate formation using the mentioned introduction system.
Figure 1 also shows the degradation of the four model compounds after treatment with LP-UV/H_2O_2, the most right bars. The reduction of Bromacil and Ibuprofen is lower compared to O_3/H_2O_2, the reduction of Atrazine is comparable, but the removal of NDMA is much higher. Although the pretreated river water had a low UV-transmission, 78%, the LP-UV lamps showed to be efficient in target compound removal. Because this technique is a UV based AOP, there is no Bromate formation. Relative high energy input is necessary to achieve significant removal, resulting in higher costs than the O_3/H_2O_2 combination.

The four green bars in the middle show the model compound degradation after combined AOP, O_3/H_2O_2 and LP-UV (2 mg/L O_3, 6 ppm H_2O_2 and different UV settings). The removal of the combined AOP is comparable or better, compared to only O_3/H_2O_2 with a higher dose (3 mg/L), especially for NDMA. The removal of combined AOP is significant higher compared to LP-UV/H_2O_2 for Atrazine, Bromacil and Ibuprofen. The removal of NDMA depends on UV dose only. By the lower O_3 dose during combined AOP compared to O_3/H_2O_2 only, the bromate formation was limited. The full paper will give a detailed discussion on the treatment costs for full scale installations (240,000 m³/d) regarding lifecycle costs, capital and operational costs for different) combinations of' AOP.

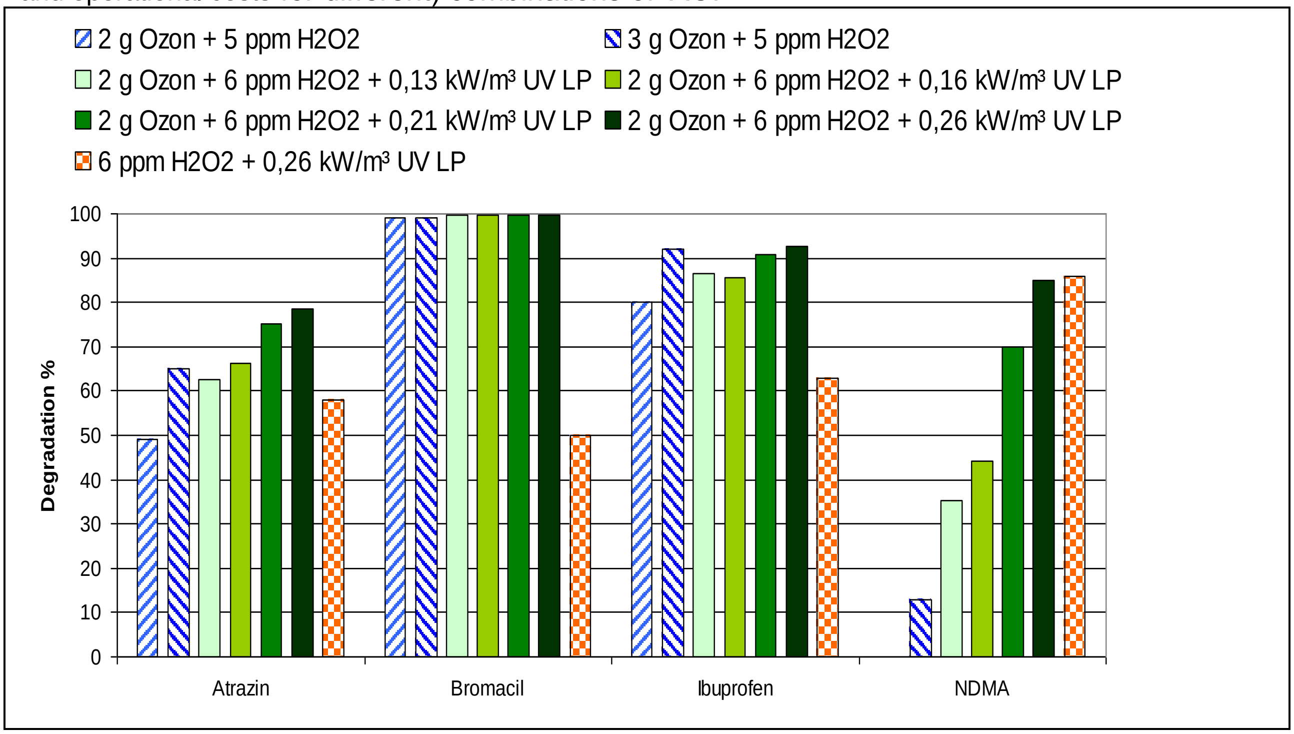

Figure 1: Degradation of four model compounds by different AOPs, UV-T influent water was 78%

Conclusion

The combination of O_3, H_2O_2 and LP-UV results in a multiple barrier treatment against OMPs, which can efficiently remove a broad range of target compounds. It is a more robust barrier for unknown substances that can become a threat in the (near) future. The dose of O_3 and UV can be lowered compared to a conventional, single AOP treatment step which uses only one of these technologies. This results in lower operational costs and lower formation of by-products such as Bromate.

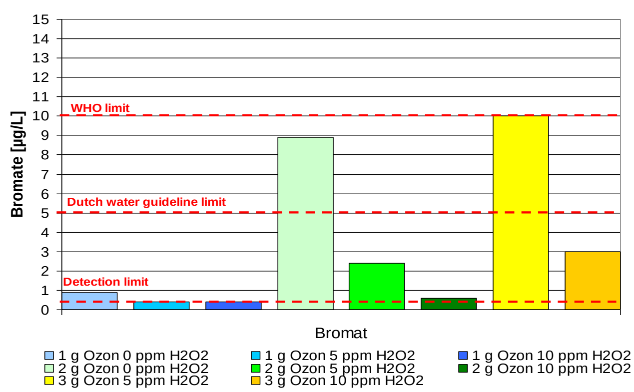

Figure 2: bromate formation

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Combination of O_3/H_2O_2 and UV
for multiple barrier micropollutant treatment and bromate formation control – an economic attractive option

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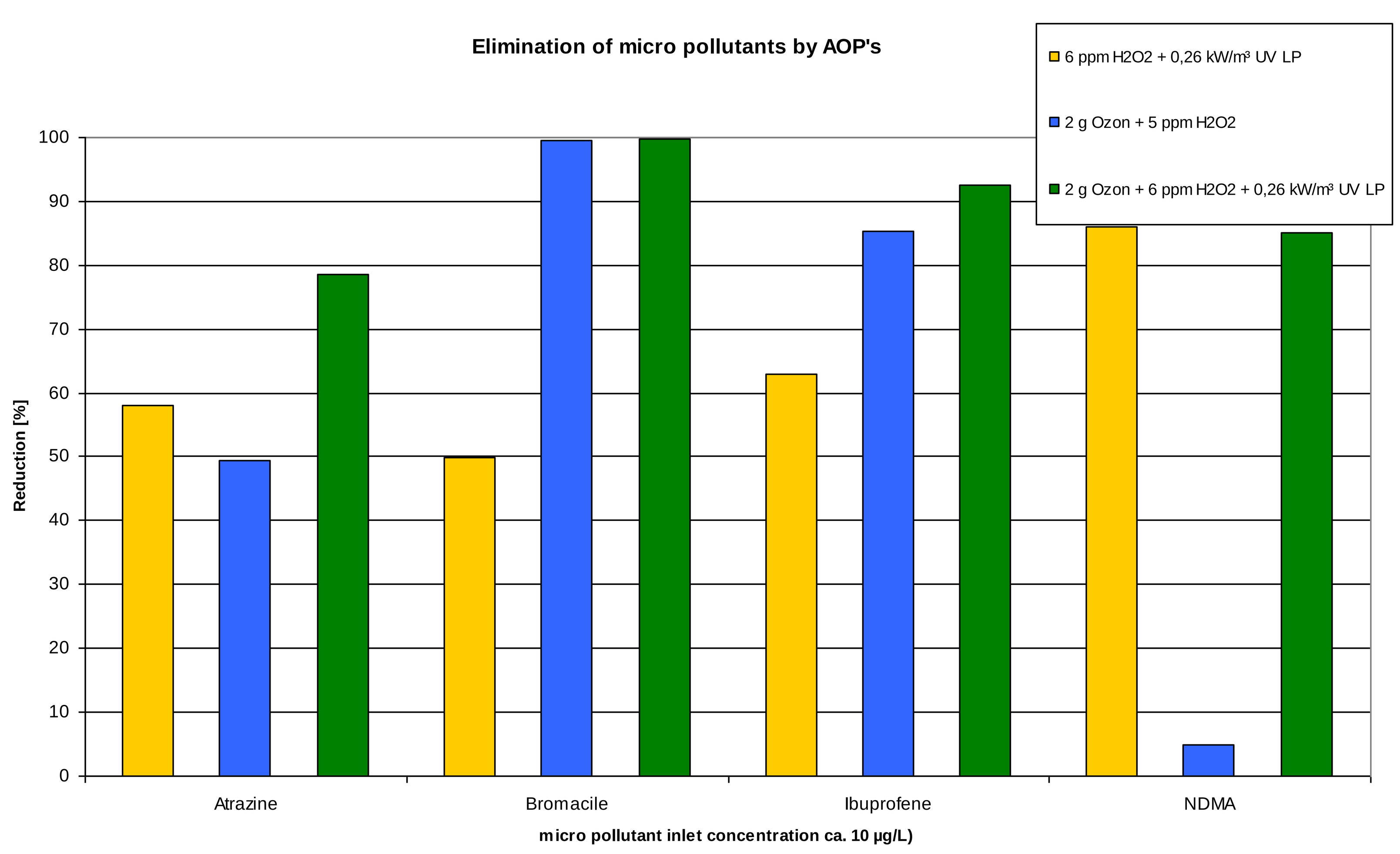
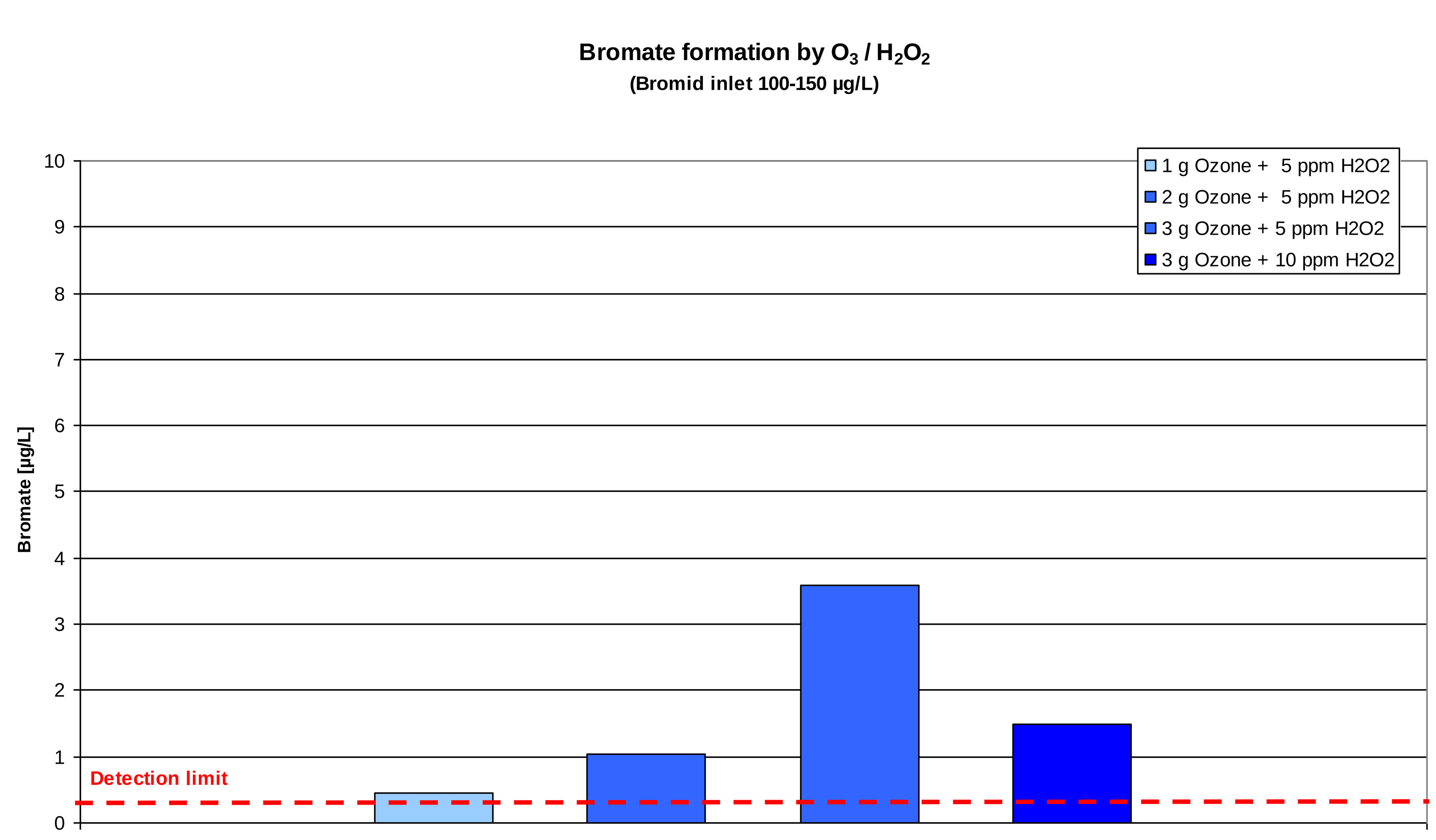
Introduction

Applying AOP's for the treatment of drinking water for the removal of micropollutants can be an energy and cost intensive solution, if the local circumstances (existing infrastructure, pre- and post treatment and water quality) and requirements are not considered properly in the design of the full scale treatment plant. Testing different technologies and their combination is vital for finding the best solution regarding treatment efficiency and reasonable treatment costs.
The tests were carried out at a water works in the Netherlands, operated by *DUNEA*. Their main requirement for an AOP treatment is the capability to target a wide range of different micropollutants and to prevent the formation of by-products such as bromate. Scope of the tests was to find that solution, which will fulfil most of the requirements.
For an economical evaluation CAPEX and OPEX calculations were carried out to identify the treatment costs for each tested solution as well as those parts, which have the highest impact on the overall costs.

Results & Discussion



This diagram shows degradation results of the four model compounds during different AOP combinations and settings. The presented results are average values of the tests carried out from March to July 2010. The combination of ozone/H_2O_2 followed by LP-UV treatment leads to the best overall degradation rates for the chosen model compounds.



As the stetting O_3/H_2O_2 in combination with LP-UV is showing good degradation rates for all tested model compounds the possible formation of bromate was investigated, as this could be a concern, when the water contains significant levels of bromide.
The diagram shows the bromate formation for different ozone dosages and peroxide ratios. In all cases the bromate formation stayed significantly under WHO limit of 10 µg/L.

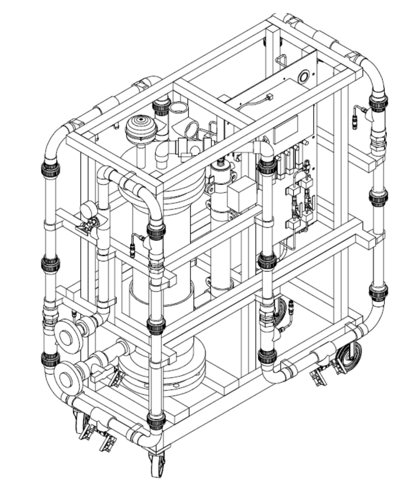
Materials & Methods

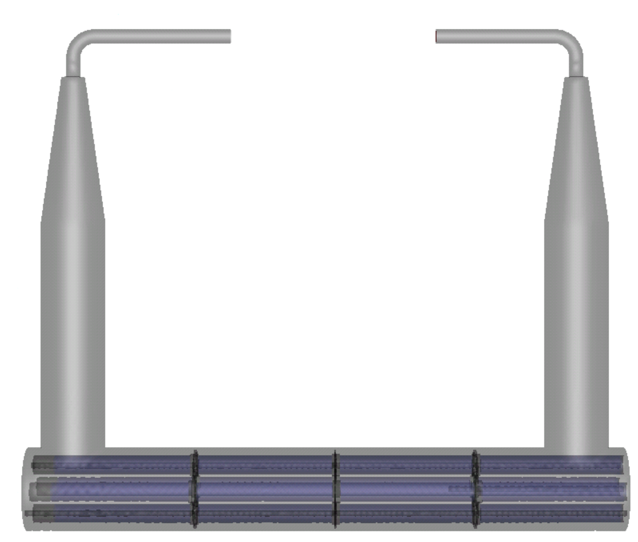
The pilot trials were carried out using surface water, which has passed a coagulation flocculation step and a rapid sand filtration. The average water characteristic is given below:

Cations		**Anoins**		**Other**			
Ca^{2+} :	59 mg/L	Br^-	: 94 µg/L	pH	: 7.9	DOC	: 3.6 mg/L
Mg^{2+} :	8.0 mg/L	HCO_3^-	: 158 mg/L	$UVT_{@254nm}$	: 81%	TOC	: 3.8 mg/L

For the pilot tests the water was spiked with Atrazine, Bromacile, Ibuprofene and NDMA. The concentration was **10 µg/L** for each compound**.**

The picture on the right shows the ozone introduction system, which was used for the ozone tests. The system consists of 6 static mixers, which are installed vertically and separated through six reaction zones. This design was chosen to limit a possible bromate formation.

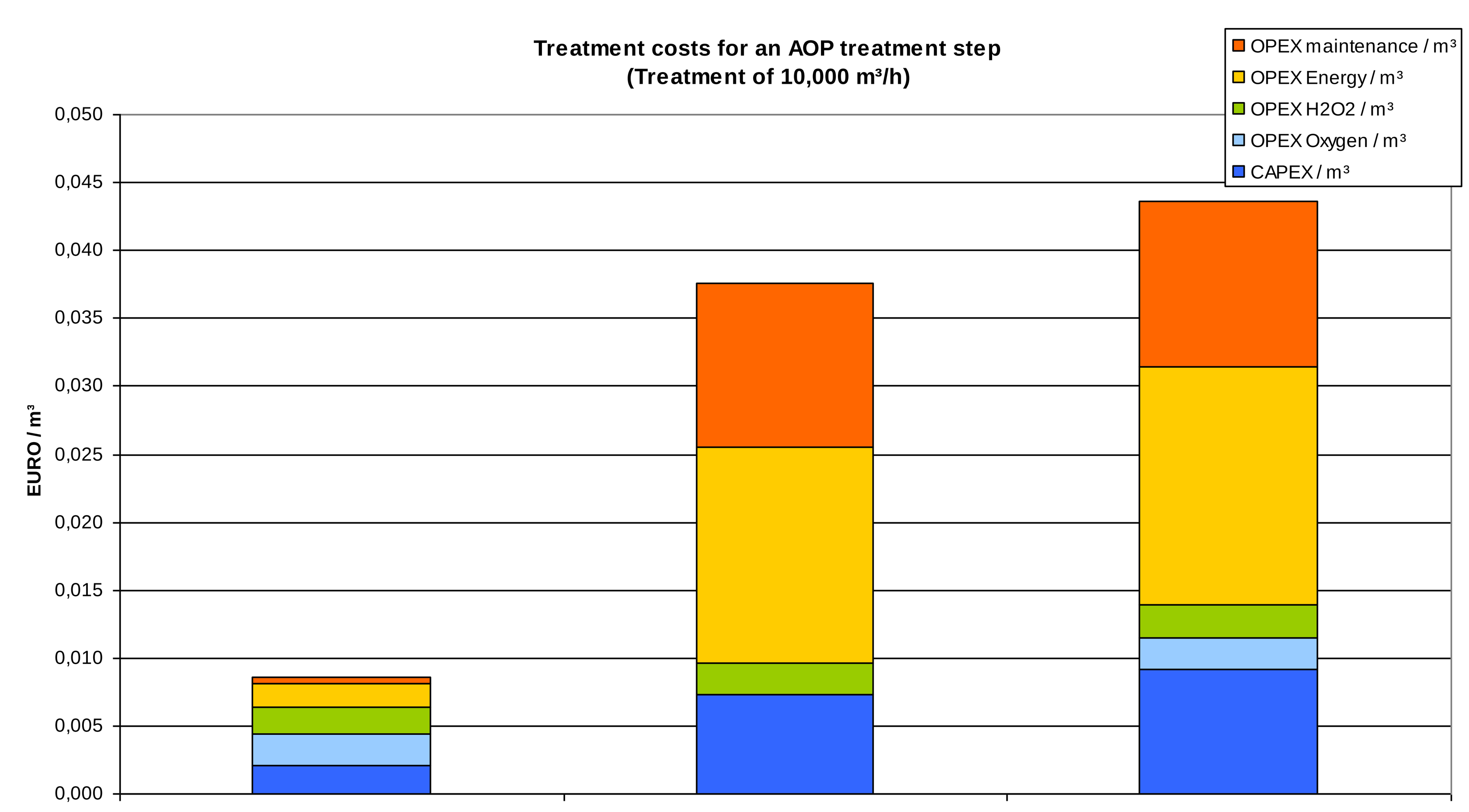




The picture on the left shows the UV reactor, which was used for the tests. The reactor consists of four low pressure lamps (LP) with a rated power of 360 W per lamp. The lamps were controlled with adjustable ballasts, which allow to dim the lamps till 50% of their maximum rated power.

All trials were carried using a continuous water flow of **5 m³/h** (**22 gpm**).

CAPEX & OPEX



The calculation for the CAPEX and OPEX are based on a full scale treatment system for 10,000 m³/h (64 MGD) and the following assumptions:

OPEX

Costs for liquid oxygen	0.17 €/Nm³
Costs for energy	0.08 €/kWh
Costs for H_2O_2	0.4 €/kg
Costs for maintenance and spares	Reference to existing plants

CAPEX

Depreciation time	20 years
Interest rate	4 %
AOP system	Reference to existing plants

Conclusions

The combination of O_3, H_2O_2 and LP-UV results in a multiple barrier treatment against micropollutants, which can efficiently remove a broad range of target compounds. It is a more robust barrier for unknown substances, which can become a threat in the future.

Depending on the water matrix (e.g. UVT, DOC, radical scavenger) and the treatment goal (reduction rate for specific target compounds) the three tools ozone, UV and H_2O_2 can be used in different combinations. For this treatment combination the best balance between reduction rates and costs was found by combining a dose of 2 g ozone and 6 g H_2O_2 per m³ with UV irradiation of 0.26 kWh rated power per m^3.

This process combination results in the lowest OPEX and CAPEX cost for a reduction rate of > 80% for the investigated compounds Atrazine, Bromacil, Ibuprofen and NDMA. In addition the bromate formation was limited to 1 µg/L.

Installing a combination of O_3/H_2O_2 and LP-UV will result in energy savings and the overall costs, including footprint and installation, are not higher compared to a single LP-UV/H_2O_2 process.